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THESIS

ANALYSIS OF HIGH-SPEED VESSELS FOR SEVENTH FLEET LOGISTICS SUPPORT

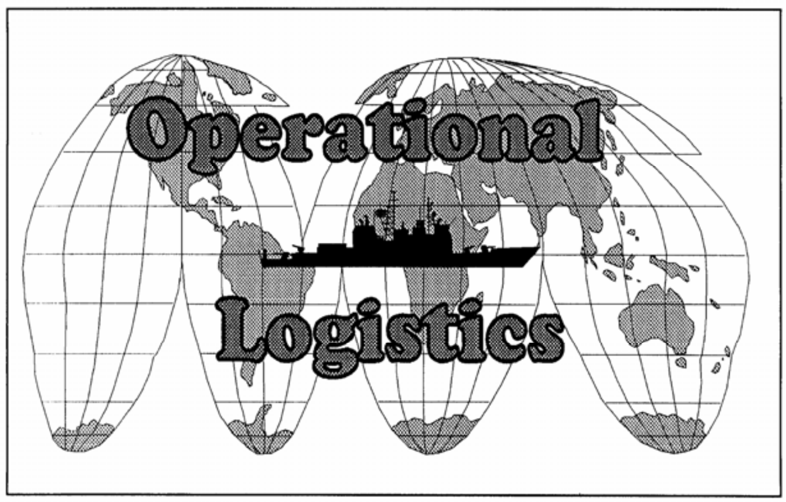
by

Eric A. Morgan

March 2005

Thesis Advisor: David A. Schrady
Second Reader: Steven E. Pilnick

Amateurs discuss strategy,
Professionals study logistics



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Commander, Logistics Group, Western Pacific (COMLOGWESTPAC) is concerned with the delivery of high priority material, ordnance, and passengers to U.S. Navy ships due to a very large operations area and limited Combat Logistics Force (CLF) assets. High-speed vessels (HSVs) may have the potential to improve the delivery of these materials when used to complement existing logistics shuttle ships. This thesis quantifies current levels of traditional naval logistics support and provides comparison to HSV-based alternatives in various scenarios. The CLF Scenario Analysis Tool (CLFSAT), a newly developed discrete event simulation model of naval logistics support, performs the analysis. Given a scenario depicting combatant movements and operations, CLFSAT provides insight into the comparative performance of different supporting naval logistics force structures.

This analysis determines that HSVs can be effective logistics platforms in specific scenarios when distributing high priority material, ordnance, and stores. HSVs are very effective in small theaters with short transit distances, but for larger theaters, their effectiveness is inversely proportional to distance from the Forward Logistics Site. Regardless of theater size, HSVs show significant improvements in theater distribution of "low density, high priority" cargo, such as precision guided munitions (PGMs) or critical repair parts when customers are outside COD range.

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ANALYSIS OF HIGH-SPEED VESSELS FOR SEVENTH FLEET LOGISTICS SUPPORT

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THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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LIST OF ACRONYMS & ABBREVIATIONS

ACTD	Advanced Concept Technology Demonstrator
ARG	Amphibious Ready Group (now ESG)
C-DAY	Deployment Operation Commences
CASREP	Casualty Report
CFFC	Commander, Fleet Forces Command
CG	Guided Missile Cruiser
CNA	Center for Naval Analyses
CLF	Combat Logistics Force
CLF OAG	Combat Logistics Force Operational Advisory Group
CLFSAT	Combat Logistics Force Scenario Analysis Tool
CNO	Chief of Naval Operations
COD	Carrier Onboard Delivery aircraft (C-2A Greyhound)
COMLOGWESTPAC	Commander, Logistics Group Western Pacific (aka CTF73)
CONREP	Connected Replenishment
CONSOL	Consolidation (Shuttle CLF to Station CLF)
CONUS	Continental United States
CSG	Carrier Strike Group
CTF73	Commander, Task Force 73 (aka COMLOGWESTPAC)
CV	Aircraft Carrier (Conventional)
CVN	Aircraft Carrier (Nuclear)
CWT	Customer Wait Time
D-DAY	Operation's assault commences or hostilities begin
DDG	Guided Missile Destroyer
DD(X)	New Destroyer Class Ship
DES	Discrete Event Simulation
DFM	Distillate Fuel Marine (NATO F76)
DoD	Department of Defense
DWT	Dead Weight Tons
ESG	Expeditionary Strike Group
FAS	Fueling at Sea
FDNF	Forward Deployed Naval Forces (Japan)
FFG	Guided Missile Frigate
FLS	Forward Logistics Site
FRP	Fleet Response Plan
HJCC	High-Speed Joint Command and Control Ship
HSC	High-Speed Connector
HSF	High-Speed Ferry

HSSS	High-Speed Support Ship
HSV	High-Speed Vessel
INREP	Inport Replenishment
JHSV	Joint High-Speed Vessel
JLOTS	Joint Logistics Over-the-Shore
JP5	Naval Aviation Fuel (NATO F44)
LCS	Littoral Combat Ship
LHA	Amphibious Assault Ship
LHD	Amphibious Assault Ship
LPD	Amphibious Transport, Dock Ship
LPF	Logistics Planning Factor
LSD	Amphibious Dock Landing Ship
MCO	Major Combat Operation
MOE	Measures of Effectiveness
MSC	Military Sealift Command
NM	Nautical Miles
NPS	Naval Postgraduate School
NWDC	Navy Warfare Development Command
ODS	Operation Desert Storm
OEF	Operation Enduring Freedom (Afghanistan)
OIF	Operation Iraqi Freedom
OPNAV N42	Office of the Chief of Naval Operations, Navy Strategic Mobility and Combat Logistics
PGMs	Precision Guided Munitions
RAS	Replenishment at Sea (not Fuel)
RO/PAX	Roll On/Off Passenger Ferry
RRT	Requisition Response Time
SSG	Surface Strike Group
SWATH	Small Waterplane Area Twin Hull
T-AE	Ammunition Ship
T-AFS	Combat Stores Ship
T-AKE	Auxiliary Dry Cargo Ship
T-AO	Fleet Oiler
T-AOE	Fast Combat Stores Ship
T-AOE(X)	Proposed and Programmed Fast Combat Stores Ship
TSV	U.S. Army Theater Support Vessel

UNREP	Underway Replenishment
VERTREP	Vertical Replenishment (via helicopter)
VOD	Vertical Onboard Delivery (via helicopter)

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EXECUTIVE SUMMARY

Commander, Logistics Group, Western Pacific (COMLOGWESTPAC) is significantly concerned with the delivery of high priority material, ordnance, and passengers to U.S. Navy ships operating in 7th Fleet. COMLOGWESTPAC considers the in-theater portion of the distribution process for these materials to be unacceptably lengthy as it relies on delivery over the "last mile" via Combat Logistics Force (CLF) shuttle ship cycles. This delay is perceived as particularly large when compared to the robust and rapid logistics support provided in 5th Fleet during Operations Enduring Freedom (OEF) and Iraqi Freedom (OIF). Unfortunately, the tyranny of distance and pure geographic nature of the theaters makes the desired 5th Fleet service levels unobtainable in 7th Fleet with the current quantities of CLF assets available. As the Navy is unlikely to increase its force structure of large, expensive CLF ships to cope with the 7th Fleet problem, it must accept reduced logistics service levels or find a more affordable option to improve them. High-speed vessels (HSVs), smaller and less expensive than current CLF ships, may improve the delivery of priority material, ordnance, and passengers when used to complement existing CLF shuttle ships in 7th Fleet.

This thesis develops the CLF Scenario Analysis Tool (CLFSAT), a discrete event simulation model of naval logistics support. Given a scenario depicting combatant movements and operations, CLFSAT provides insight into the performance of different supporting naval logistics force structures. The simulation is used to determine whether addition of HSVs in a logistics role significantly improves customer service levels for combatant ships in the 7th Fleet Theater of Operations. The analysis specifically examines distribution of "low density, high-priority" material, in terms of critical repair parts, and precision guided munitions (PGMs).

A hypothetical Major Combat Operation (MCO) in Korea forms the basis for two analyzed scenarios. The Fleet Response Plan (FRP) and forces available in May 2005 inform combatant availability and resulting operations. The first scenario assumes availability of preferred Forward Logistics Sites in Japan. CLFSAT quantifies logistics performance differences between a base case using current CLF force structure and an excursion adding two HSVs. Results from this comparison suggest a second excursion, which includes the two HSVs while reducing the current CLF force structure. The second scenario hypothesizes a North Korean nuclear blackmail of Japan, forcing the withdrawal of access to Japanese logistics ports. The closest assured Forward Logistics Site is then Guam, at 1800-plus nautical miles. CLFSAT determines a new baseline, which has a larger current CLF force structure due to the increased distances. It then quantifies logistics performance differences between that baseline and an excursion adding two HSVs.

Results indicate that HSVs can be effective logistics platforms in specific scenarios with limited tasks. They display effectiveness in the distribution of high priority material, ordnance, and stores. These are either required less often and in smaller quantities than other commodities, or have a time component that drives the need for rapid delivery. HSVs are very effective at supplying these commodities in small theaters with short transit distances, but for larger theaters, their effectiveness is inversely proportional to the distance from the Forward Logistics Site (FLS). In these small theaters with a nearby FLS, as around Korea with close support in Japan, HSVs allow the naval logistics system to "touch" each customer every 36-48 hours. Additionally, their high-speed gives HSVs "virtual capacity", allowing them to act in place of some larger CLF shuttle ships, such as T-AEs, T-AFSs, or T-AKEs. This commodity resupply capability evaporates with increasing distance from the FLS.

The niche mission where HSVs appear most effective is theater distribution of "low density, high priority" cargo; whether that cargo is precision guided munitions (PGMs), critical repair parts, or people should not matter. This holds true in small theaters (e.g., Korea or the Arabian Gulf), where specifically tasked HSVs can deliver material up to ten times faster than current CLF, and in larger theaters, where up to four times faster is still possible. This area of "customer service", of the most concern to COMLOGWESTPAC, is also the area that shows the most benefit from HSVs. The improvements gained from HSVs should be the most apparent for cargos too large for COD, at distances greater than COD range, or for ships not operating with a CSG.

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I. INTRODUCTION

A. LOGISTIC SUPPORT OF SEVENTH FLEET OPERATIONS

Commander, Logistics Group, Western Pacific (COMLOGWESTPAC) is significantly concerned with the delivery of high priority material, ordnance, and passengers to Carrier Strike Group (CSG) escort ships and all Expeditionary Strike Group (ESG) ships. COMLOGWESTPAC, operationally known as Commander, Task Force 73 (CTF 73), is the U.S. 7th Fleet's principal logistics agent for Southeast Asia. The command plans the resupply of food, ordnance, fuel and repair parts for U.S. Navy ships deployed to the 7th Fleet area of operations. This area of responsibility (AOR), illustrated in Figure 1 below, includes over 52 million square miles of the Pacific and Indian Oceans -- stretching from the International Date Line in the mid-Pacific to the east coast of Africa and from the Kuril Islands in the north to the Antarctic in the south [Ref. 1]. Current COMLOGWESTPAC logistics operations and plans rely on assigned Combat Logistics Force (CLF) shuttle ships to deliver high priority material, ordnance, and passengers to the customer ships. These CLF shuttles regularly cycle between loading cargo in logistics shuttle ports and delivering that cargo to customer ships via underway replenishment (UNREP). The delay between a customer's request for high priority material and its delivery onboard is called Customer Wait Time (CWT). COMLOGWESTPAC considers the portion of CWT under their control to be unacceptably lengthy as it relies on delivery over the "last mile" via these CLF shuttle ship cycles. This delay is perceived as particularly large when compared to the robust and rapid logistics support provided in 5th Fleet during Operations Enduring Freedom (OEF) and Iraqi Freedom (OIF).

The impetus for perceived disparities in naval logistics support between the fleets is the recent profusion of operations based in the 5th Fleet Theater. Twenty years of near continuous naval operations in the 5th Fleet region, including four major operations, Operations Earnest Will/Praying Mantis, Desert Storm (ODS), Enduring Freedom (OEF), and Iraqi Freedom (OIF), have created somewhat unrealistic expectations of robust naval logistics support that is unavailable anywhere else in the world.

Figure 1. **7^{th} Fleet Area of Responsibility (AOR) with key logistics ports**

1. 5^{th} Fleet versus 7^{th} Fleet Logistics Support

Geographic factors and the nature of the support structure in 5^{th} Fleet make any comparisons with the rest of the world specious. The 5^{th} Fleet Area of Responsibility (AOR) covers approximately 6.4 million square miles compared with 52 million square miles for 7^{th} Fleet. Amplifying this scale difference, most 5^{th} Fleet operations occur very close to logistics support ports. The majority of operations occur in the Arabian Gulf with support from Bahrain and Jebel Ali (never more than 200 nautical miles), followed by the Red Sea with support from Djibouti and Jeddah (never more than 400 nautical miles), and the Northern Arabian Sea with close access to Fujairah (usually less than 500 nautical miles). These relatively short distances are matched in 7th Fleet only in the operations areas around Korea and Japan, while in the rest of the theater replenishments can easily be more than 1000 miles from logistics ports.

The "small lake" effect of the shorter distances in 5th Fleet allows not only a rapid turnaround of the relatively slow CLF shuttle ships, but extensive use of logistics air assets for Carrier Onboard Delivery (COD) services via C-2s and Vertical Onboard Delivery (VOD) services via helicopters. For this purpose, 5th Fleet has organic H-3, H-53 and MH-60S logistics helicopters, C-2 CODs, and C-130 transports. These air assets allow next-day service for high priority material and passengers, contributing to the perception of fast service and short CWTs in 5th Fleet. 7th Fleet has no equivalent organic air assets, nor would they be able to use them in the majority of their AOR due to excessive ranges.

Differences in theater naval logistics support schemes also affect the frequency of replenishment. 5th Fleet regularly strips the CLF station ships from the Carrier Strike Groups (CSGs) to be used as shuttle ships. This increases the number of shuttle ships available, and thus reduces the shuttle cycle times. Given the longer transit distances in the 7th Fleet AOR, stripping the station ships from the CSGs is infeasible due to the long shuttle cycles, though it could be possible in the relatively small operations area around Korea and Japan.

2. Naval Logistics Support during Operations Enduring Freedom (OEF) and Iraqi Freedom (OIF)

In addition to the pure theater differences, the nature of the operations in 5th Fleet contributes to the perception of reduced logistics support in 7th Fleet. The large percentage of U.S. Naval forces that participated in Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF) established precedents for naval logistics support. The Center for Naval Analyses (CNA) has analyzed CLF performance in both of these operations extensively, but only the portions of those reports pertaining to delivery of high priority material, passengers, and ordnance is relevant to this analysis [Ref. 2 & 3]. In 5th Fleet, where both OEF and OIF took place, high priority material and passengers are usually delivered by COD or VOD, if available; otherwise they must be transported on a CLF lift of opportunity and delivered via UNREP. One method of providing visibility into the level of customer service provided is to look at the number of days between replenishments for the customer ships. This "customer-centric" measure is sometimes incorrectly called cycle time, which more accurately describes the "CLF centric" time required for a CLF ship to shuttle from a logistics port to customer and back. CNA categorized this OEF data by customer ship type and examined it in two ways: days between replenishment type (COD, VOD, or Replenishment at Sea (RAS)) as presented in Table 1, and days between specific commodity replenishments (Dry Stores, Fuel, or Ordnance) as presented in Table 2.

Hull Type	COD	VOD	RAS
CV/CVN	0.8	2.6	3.0
Amphibs	-	11.3	4.6
CG	-	8.0	3.6
DD/DDG	-	6.2	3.9
FFG	-	8.3	3.2

Table 1. OEF: Average number of days between specific replenishment events by customer type, 8/1/01 – 3/31/02. [From Ref. 2]

Hull Type	Dry Stores	Fuel	Ordnance
CV	3.8	4.2	11.0
CVN	3.8	6.5	7.4
Amphibs	5.3	8.2	32.3
CG	5.1	5.1	31.7
DD/DDG	6.6	4.9	39.1
FFG	5.9	4.6	52.8

Table 2. OEF: Average number of days between replenishment events by customer type and commodity, 8/1/01 – 3/31/02 [From Ref. 2]

Unfortunately, CNA aggregated these numbers in Table 1 and 2 over an eight-month period covering three distinctly different operational profiles: Pre-September 11th, Pre-OEF, and OEF. This wide variance in naval operations throughout the period would have a big effect on these frequency numbers, so it is not clear how valid they might be without segregating them into the three operational profiles. For example, the average number of days between ordnance replenishments from Table 2 is highly suspect, given that the first two periods, Pre-September 11th and Pre-OEF, do not involve ordnance expenditure, so would not require ordnance replenishment. So, short of eliminating these periods from the calculation of the averages, one quarter of the total time period without ordnance replenishments would have a large impact on the average values.

Despite the high aggregation of the OEF data, the same granularity is not even available for OIF. The only OIF customer service or replenishment frequency data available is for aircraft carriers. The carriers on the Mediterranean Station (6th Fleet not 5th) averaged UNREPs every 2.9 days, while those in the Arabian Gulf averaged UNREPs every 3.6 days. For the Arabian Gulf, this is slightly less often than in OEF, but OIF had a much higher customer to CLF ratio during the peak operations, 5.8 customers to 1 CLF, as compared with 3.6 to 1 for OEF. [Refs. 2 and 3]

These OEF and OIF numbers show at least adequate, or in some cases, excellent customer service, but can still be slightly misleading. From the OEF data, all ship types averaged receiving dry stores every 4 to 6 days. This is well above what is actually required for sustainment of combatants, so it is not clear if this was driven by parts requirements, or simply provided due to an excess of CLF in 5th Fleet. When looking specifically at high priority material and ordnance, actual performance could be even better than shown by the aggregated values in the tables. For example, the use of averages hides the CODs and VODs that handled emergent high priority requirements on a same or next-day basis. As mentioned earlier, this level of rapid service is very often possible in 5th Fleet as during OEF and OIF, and rarely possible in 7th Fleet. In the cases when VODs are not possible due to range, customer ships must rely on CLF shuttle ship RAS for high priority material delivery. In 5th Fleet, during both OEF and OIF, RAS was available, on average, every 3 to 4 days, which in most cases is still quite rapid. These low shuttle ship cycle times are very hard to achieve in 7th Fleet, with 8 to 12 days being much more likely.

B. HIGH-SPEED VESSELS AS CLF – AN AFFORDABLE OPTION?

The tyranny of distance and nature of the theater makes the desired 5th Fleet service levels unobtainable in 7th Fleet with the current quantities of CLF assets available. Unfortunately, these traditional CLF ships are large, expensive vessels, and the U.S. Navy is on a declining force structure trend imposed by fiscal constraints. While there are current and planned programs to build new replenishment ships, much of current dialogue focuses on reducing the number of these large, expensive CLF ships that we buy and operate. The declining force structure trend has forced the majority of recent studies to focus on how to improve employment of the existing CLF forces and some of these attempts to optimize CLF schedules have grown into a push for global vice theater scheduling of CLF assets. All of these machinations are intended to counteract the reduced inventory and procurement numbers, but do not fully answer the 7th Fleet tyranny of distance problem. As the Navy will be constrained by these fiscal realities for the foreseeable future, they cannot simply buy more traditional CLF assets to cope with the 7th Fleet problem. The Navy thus has the choice of accepting the reduced logistics service levels in 7th Fleet or finding some other less expensive option to improve them.

High-speed vessels (HSVs) have the potential to provide the desired rapid delivery of priority material, ordnance, and passengers when used to complement existing CLF shuttle ships in 7th Fleet. These high-speed vessels (HSVs) have an advanced hull form, such as the wave-piercing catamaran, and can transit at high-speeds (30 to 45+ knots). HSVs trade speed and reduced cycle time for a much lower cargo capacity and endurance than traditional CLF. They are also significantly less expensive to procure and operate, making them a potential fiscally feasible solution. Variants of the HSV are under consideration to play a large future role in Sea Power 21 and become a key part of naval transformation.

A HSV designed as a support ship could prove particularly useful in the 7th Fleet where VOD services are not available or COD assets are outside practical range from shore logistics bases. Conversely, the short distances in the small operations areas around Korea (much like most parts of 5th Fleet) combined with the high speed of the HSVs could make them attractive for some very high priority cargos, particularly precision guided munitions (PGMs) that may be in short supply. Given the recent U.S. Navy HSV experimentation, COMLOGWESTPAC considers the HSV a potential solution to their Customer Wait Time (CWT) issue. U.S. Pacific Fleet and 7th Fleet agree and have assigned COMLOGWESTPAC as the lead agency to conduct a study on the HSV's potential logistics mission and secondary missions supporting operations, contingencies, and Operational Plans (OPLANS) in 7th Fleet. This thesis research is undertaken in support of COMLOGWESTPAC.

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II. BACKGROUND

A. OPERATIONAL LOGISTICS IN THE U.S. NAVY

Modern naval operations and Sea Power 21, the U.S. Navy's vision for the future, are dependent on naval operational logistics for success. When the Chief of Naval Operations, Admiral Vern Clark, talks about the Navy, he emphasizes the value of persistence:

> One of the things that I have learned over the course of the last year and a half is the importance of persistence. When I got this job, I realized I had to be able to talk about the Navy, the vision for the Navy, and what our mission and task and function were. I can do that for an hour, and I can do it for 30 minutes, or 15, or 10. And sometimes I only have 30 seconds. The 30-second version is: credible combat power, far corners of the earth, sovereignty of the United States of America, anywhere we want to go without asking permission. In the aftermath of Afghanistan, I added the P word-not just credible combat power, but credible, persistent combat power. So persistence is one of my favorite words. [Ref. 4]

Persistence as a naval capability is reliant on many factors but is not possible without a robust naval operational logistics system. The U.S. Navy is the world's most proficient practitioner of naval operational logistics and has been since developing the initial procedures for underway replenishment (UNREP) in 1904. From the first oiler, USS KANAWHA (AO-1), to the newest underway replenishment ship, the USNS LEWIS AND CLARK (T-AKE 1), the U.S. Navy remains committed to robust naval logistics support. Throughout the history of U.S. Navy operational logistics, the basic support paradigm has remained the same: underway replenishment of combatants by large and usually slow auxiliary shuttle ships. The methods of UNREP have been refined and improved with increasing capacities for connected replenishment (CONREP), the addition of vertical replenishment (VERTREP) via helicopter, and the introduction of Fast Combat Support station ships (AOEs), but the basic support paradigm remains relatively static. Sea Power 21 brings some new focus onto this area, mainly in the Sea Basing concepts. To support these concepts, engineers are significantly increasing CONREP capacities to handle significantly heavier loads and small shipping containers.

Despite these marginal improvements, current and future CLF plans rely on building and using more of the same types of replenishment ships that we have been using for 40 years. The Navy's fiscal limitations and declining force structure trend provides impetus to investigate alternative methods that bear little resemblance to traditional CLF operations. This study for COMLOGWESTPAC on the potential of HSVs is one such alternative method.

B. COMMERCIAL HIGH-SPEED VESSELS

The commercial market for high-speed ferries (HSFs) drives the development of HSVs. Through the 1980s, the commercial HSF industry was a small niche business dominated by Norway with a hybrid mono-hull hydrofoil design known as the asymmetric catamaran. Technological advances in aluminum shipbuilding and water jet propulsion in the 1980s allowed the development of the symmetric catamaran, which springboarded the rapid rise of the HSF industry and fostered new dominance by Australian Shipbuilders, Incat and Austal. By 1990, this new technology had developed vessels capable of carrying 449 passengers at speeds in excess of 35 knots [Ref. 6]. Continued improvement in engine and hull-technology has allowed larger and faster vessels carrying heavier loads shifting much of the business from passenger-only to combined passenger and car ferries. In 1997, the CAT LINK V, a wave-piercing catamaran designed and built by Incat of Australia crossed the Atlantic, while light-loaded, at an average speed of 41.28 knots. Making this feat more remarkable is the relatively large size of the vessel: the 34,000 horsepower ferry is 91.3 meters length overall and has the capacity to carry 800 passengers and 200 cars, although at lower speeds.

The high-speed of HSFs given their large size is not without a price. The combination of these factors requires high horsepower engines with high power-to-weight ratios. Medium and high-speed turbo-charged diesels dominate the HSF industry as they provide acceptable speed and are more fuel-efficient. Gas turbines have a higher power-to-weight ratio which leads to faster top speeds with more cargo but also worse fuel economy. [Ref. 7] The "iron triangle" of balancing cargo and fuel weight (payload) with range and speed requirements is a continuous and critical process for all HSFs. Gaining additional range and/or speed, requires additional fuel, thus directly reducing cargo capacity. The range of the ferries varies with the amount of cargo versus fuel load as described in Figure 2 below. As an example, an Incat 98-meter vessel, at 35 knots, can carry 720 tons of cargo 200NM, but by limiting cargo to 270 tons, can achieve ranges of 3000NM. The capacities for cargo reflect crew, passengers, cargo, water, etc. [Ref. 6]

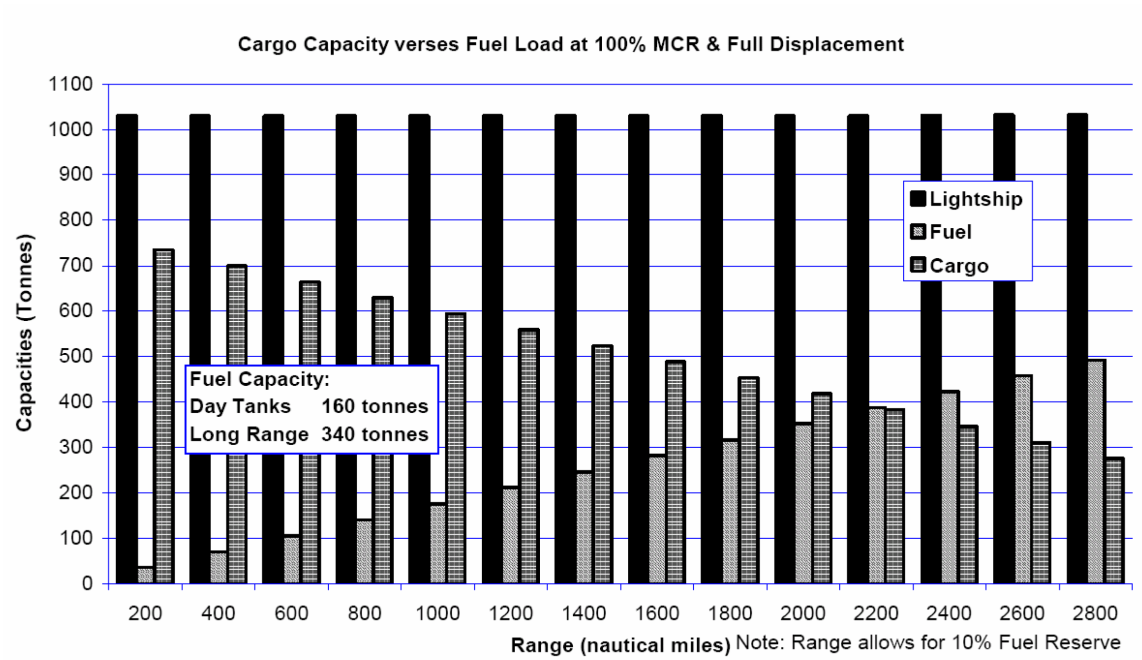

Figure 2. Incat Evolution 10B 98m Platform: Cargo Capability vs. Fuel Load at 100% MCR and Full Displacement [From Ref. 6]

Today, Incat's fast wave-piercing catamaran and Austal's not nearly as fast, but more stable, forward Small Waterplane Area Twin Hull (SWATH) catamaran designs dominate the HSF industry. Both designs result in a broad platform with a large amount of internal deck space for vehicles and cargo and are sometimes referred to as RO/PAX vessels, for Roll-On/Roll-Off and Passenger. While there are other smaller HSF builders in Japan and Norway, as well as other companies in Europe and the U.S. experimenting with trimarans, pentamarans, and new mono-hull designs, the two Australian companies have drawn the military interest in HSVs.

C. MILITARY USE OF HIGH-SPEED VESSELS

1. HMAS JERVIS BAY

In 1999, the Royal Australian Navy signed a two-year lease for an Incat 86m HSF, the HMAS JERVIS BAY, to fill an amphibious lift shortfall caused by the unavailability of two recently purchased former U.S. tank landing ships (LSTs) still undergoing conversions. The HMAS JERVIS BAY, pictured in Figure 3, is a completely commercial design; the only military modifications were a gray paint scheme and slightly strengthened lower decks. High levels of automation allowed operation and loading of the ship by a 25-person Navy crew.

The first tasking for the JERVIS BAY was supporting Australia's contribution to the humanitarian operations in East Timor. On her first journey from Darwin, Australia to Dili, East Timor, she carried 572 soldiers and their equipment 430 nautical miles in less than 12 hours, sustaining speeds over 40 knots. This was the first military operation conducted by a HSF, soon to be relabeled by the military as a high-speed vessel (HSV). Over the next year, the JERVIS BAY traveled the Darwin to Dili route 74 times, carrying supplies, troops, armored personnel carriers, light armored vehicles, trucks, refrigerated containers and standard cargo containers. During these missions, the ship rapidly self-loaded and self-offloaded at austere ports and even performed at-sea transfers to landing craft. [Ref. 6]

The United States' first introduction to military HSV use occurred during an inter-operability exercise between JERVIS BAY and the TARAWA Amphibious Ready Group (ARG) in September 2000. During the exercise, JERVIS BAY loaded U.S. Marines and U.S. Navy SEALs from the ARG at-sea, inserted them into an exercise area, then recovered and returned them to the ARG, all while the ARG remained 200 nautical miles offshore. [Ref. 6]

Figure 3. HMAS Jervis Bay [From Ref. 9]

2. WestPac Express

After exposure to JERVIS BAY, III Marine Expeditionary Force (III MEF), based in Okinawa, Japan, used Military Sealift Command (MSC) to lease the WestPac Express in February 2002 on a time charter. III MEF uses the 101m Austal HSV, pictured in Figure 4, to support lift requirements for training and operations in the Western Pacific Region between Okinawa, Guam, Thailand, Korea, and the Japanese mainland. Before this lease, III MEF was reliant on U.S. Air Force airlift. The WestPac Express is capable of sustaining 36 knots while transporting 500 dead weight tons (DWT). In 40 hours, it was able to transport 370 Marines and 400 tons of cargo between Okinawa and Guam (1200nm). At the high end, it has transported 970 Marines and 550 tons of equipment in a single load from Okinawa to Yokohama (600nm). To move the same amount via airlift would take 14-17 airlift assets spread out over a 14 day period. [Ref. 8] The overwhelming success of the WestPac Express trial led to the signing of a new three-year lease by MSC.

Figure 4. WestPac Express [From U.S. Navy]

3. HSV-X1 JOINT VENTURE

Seeing the potential for increased U.S. military contracts, Incat Australia partnered with Bollinger Shipyards to form Incat USA to design and produce HSVs to U.S. specifications. The newly formed company's first contract in July 2001, was for the U.S. Department of Defense (DoD) lease of a 96m wave-piercing catamaran, Incat Hull 050. This vessel, originally launched in 1998, was the first of Incat's 96m class. TT-Line (Tasmania) initially operated the vessel as the DEVIL CAT for Bass Strait crossings. It then moved to New Zealand, operated by Fast Cat Ferries to provide service across the Cook Strait as the TOP CAT. This continued until Tranz Rail forced Fast Cat Ferries out of business with anti-competitive practices, since prosecuted. The vessel was returned to Incat, where it was modified for military use and renamed by DoD as the HSV-X1 JOINT VENTURE to be used for multi-service evaluation and experimentation. Incat modified the vessel for military use by adding a helicopter deck, stern quarter RO/RO ramp, RHIB deployment gantry crane, full seating and limited rack accommodations for 363 troops, crew accommodation, storage facilities, medical facilities, long-range fuel tanks, and a C4ISR room. HSV-X1, pictured in Figure 5, has a shallow loaded draft of 12 feet and is capable of self-deployment over 4500 nautical miles. It is able to transport a cargo load of 422 short tons for 1110 nautical miles at an average speed of 35 knots in sea state 3. Alternatively, it can carry 545 short tons for 600 nautical miles, also averaging 35 knots in sea state 3. [Ref. 9]

The Navy, Army, Marine Corps, and Special Operations Command split experimentation with JOINT VENTURE. The Army used the vessel to evaluate and experiment with concepts related to the transformation to the Objective Force. The Navy used it to test concepts for the Littoral Combat Ship (LCS) and Mine Countermeasures, and the Marine Corps experimented with Sea Basing concepts. The experimentation was suspended when JOINT VENTURE deployed operationally to the Arabian Gulf for OIF. During OIF, JOINT VENTURE performed superbly while operating in the littorals of Iraq as an Afloat Forward Staging Base for Navy Special Warfare combatant craft operations. Since this Special Operations use, Army and Marine Corps Forces in Central Command used her to support intra-theater lift. The Army recently bought out the Navy share of HSV-X1 and continues to operate the vessel.

Figure 5. HSV-X1 Joint Venture landing a MH-60S Knighthawk [From U.S. Navy]

4. U.S. Army TSV-1X SPEARHEAD

After one year of operating the JOINT VENTURE, the Army decided that they needed another HSV as an Advanced Concept Technology Demonstrator (ACTD) program. USAV TSV-1X SPEARHEAD is Incat Hull 060, a modified 98m Evolution 10B wave-piercing catamaran. Her purpose is to demonstrate and evaluate her ability to perform during specified missions in a theater support role, making sustainment deliveries and moving Army pre-positioned supplies and troops. The Army wants to use a fleet of TSV-like vessels to transport units within a theater of operations in hours instead of days. The TSV supports the intra-theater movement portion of the Army's Transformation goal of deploying a combat ready brigade anywhere in the world within 96 hours, a division in 120 hours and five divisions within 30 days [Ref. 9]. Immediately after delivery, SPEARHEAD deployed to Central Command to support OEF and OIF.

Figure 6. USAV TSV-1X SPEARHEAD Advanced Concept Technology Demonstrator [From Ref. 9]

5. HSV-2 SWIFT

Based on the successful experimentation with JOINT VENTURE, the Navy acquired their own Incat 98m catamaran, Hull 061, renamed the HSV-2 SWIFT on 15 August 2003. Further improvements made to SWIFT include a much larger flight deck with two hangers for MH-60S helicopters, an improved crane capable of launching boats and unmanned vehicles, a robust Navy communications suite, and an interface system for modular payloads. SWIFT is primarily serving as an interim replacement for the mine warfare command and control ship, USS INCHON. The Navy Warfare Development Command is also using SWIFT to continue testing LCS concepts, while the Marine Corps is testing Sea Basing concepts. Since delivery, SWIFT has deployed to West Africa & Norway, and tested Joint Logistics Over the Shore (JLOTS) off South America.

In January 2005, SWIFT deployed to South East Asia to support Operation Unified Assistance, the humanitarian operation in the wake of the recent tsunami.

Figure 7. HSV 2 SWIFT with MH-60S Knight Hawk on deck. Note dual hangers [From U.S. Navy]

6. Future Designs

Incat has designed a longer and wider 112m catamaran intended for military applications with several variants possible. The CNO considered a High-speed Joint Command & Control (HJCC) variant fitted out as a joint command post as a replacement for existing large command ships. While this HJCC design was promising, it lost out in the competition with traditional combatants for now extremely limited shipbuilding funds. A High-speed Support Ship (HSSS) cargo variant takes advantage of the broader, longer platform to provide higher cargo capacities and endurance, roughly 800+ tons at 3500nm at 35-45 knots. This variant has a much larger flight deck for two or more helicopters and is optimized for a CLF of fast sealift sort of role. It is the current prime candidate for the Joint High-speed Vessel (JHSV) program, run by the Navy, with Army and Marine Corps participation. This thesis uses the HSSS variant of the Incat 112m Sea Frame to evaluate HSVs as CLF ships.

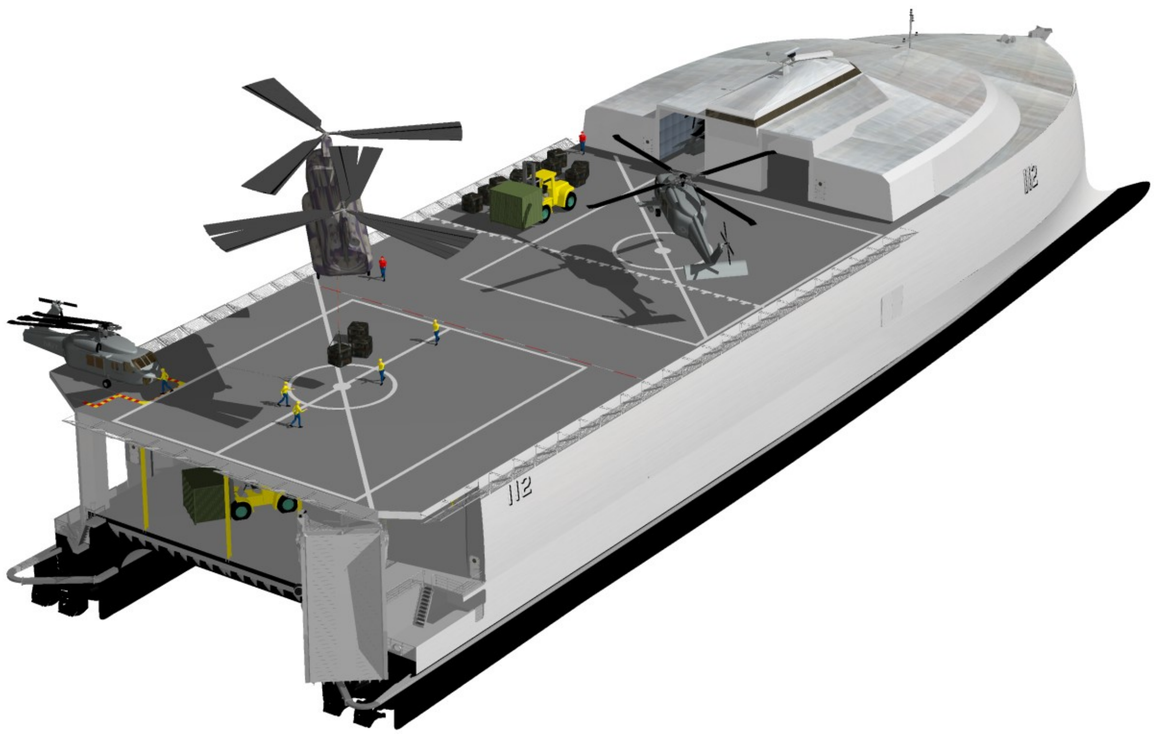

Figure 8. Incat 112m High-speed Support Ship with large flight deck [From Ref. 9]

7. Sea Basing and the High-Speed Connector (HSC)

Sea Basing is part of the Navy's Sea Power 21 vision. The sea base is intended to provide naval forces with the capability to loiter, project, and sustain significant combat power from the sea in an anti-access environment. To make the sea base work, a system of high-speed connectors (HSCs) is required to network the sea base to the continental United States (CONUS), to advanced bases, and to forces operating ashore. Within the sea base, the connectors will interface with prepositioning ships, commercial and CLF shipping, and the assault and strike platforms of the ESG and CSG. There are three types of connectors required: Intertheater to connect CONUS and advanced bases or the sea base, Intratheater to move forces from advanced base to sea base and operationally within the theater, and Assault/Lighterage connectors to move combat forces ashore [Ref. 10]. The concept for the Intratheater HSC shares many of the same characteristics as the HSVs discussed earlier. HSV 2 SWIFT actually performs much of the current experimentation with HSC concepts. If DoD procures Intratheater HSCs, they may be a completely new design or leverage existing designs, such as the Incat HSVs. Whichever design, Sea Basing studies indicate that these Intratheater HSCs must be forward based in the theater in which they will be employed in order to be available to support the Sea Base. With these Intratheater HSCs deployed in the operational theaters for use in wartime, they are potentially untasked in peacetime. Establishing a potential peacetime logistics role for these HSCs, and examing how they could perform in a wartime CLF role could provide further justification and support for the Sea Basing concept.

D. EXISTING STUDIES OF HSV USE

1. Center for Naval Analyses (CNA)

The ubiquitous Center for Naval Analyses (CNA) has done some of the initial work in this field. They have three studies that apply directly:

a. Application of Speed in Naval Vessels

This study examines the historical uses of speed in the U.S. Navy and finds there is no singular case where speed is a dominant ship design characteristic. Speed does have value and can provide a significant increase in ship capability when combined with other characteristics, such as a useful load-carrying capability. The authors initially focus on speed in combatant ships and make the argument that speed placed in the weapons (i.e., missiles) is much more critical. They also make the point that combatant ships spend the majority of their time at their most efficient speeds, making fuel use the dominant driver. While this is a valid finding for combatants, it has much less application to logistics operations where payload capacity divided by transit and cycle times directly drive sustainability. If high-speed is the only thing that makes the sustainment possible, then high-speed will be used despite the inefficiency and high fuel consumption required if it can satisfy the payload requirements. The authors provide support for this by examining CLF operations in 5th Fleet during OEF and finding that the shuttle ships increasingly had to proceed at maximum speed to meet requirements. They also mention that for sea basing and intratheater movements, the combination of speed, lift capacity, and equipment handling capabilities combine to make a militarily significant capability and that experimentation with HSVs has shown that "speed clearly helps".

CNA makes the final point that the availability of intermediate support bases for loading CLF ships is decreasing, due mostly to force protection concerns. This results in the distances traveled by shuttle ships increasing, which drives a requirement for more shuttle ships or ones with increased speed [Ref. 11]. Alternatively, a HSV with a large fuel load (thus range) and small payload might fill a niche requirement if adequate payload throughput could be achieved.

b. Quicklook Investigation of a High-speed Vessel's Utility as a Combat Logistics Force Ship

The Director, Strategic Mobility and Combat Logistics Division (N42), in the Office of the Chief of Naval Operations (CNO) asked CNA to assess alternative concepts for CLF ship deployments. This quicklook study answers that tasking by investigating HSV's utility as an alternative CLF platform delivering logistics products—fuel, ammunition, and/or dry stores—to customer ships. To perform this analysis, CNA used two notional HSVs. The current technology HSV-600 has a cargo payload of 600 tons, a range of 1,000 nm, and a full-load speed of 35 knots. The future technology HSV-1250 has a cargo payload of 1,250 tons, a range of 3,000nm, and a full-load speed of 40 knots. The study had the following main findings:

> The fuel capacity of both notional HSVs is too small for refueling task force/unit customers. Thus, they are ineffective as wet product ships. Because customer ships normally require stores replenishment only once every 10 to 15+ days, the speed advantage of an HSV is of limited value in this role … Our findings indicate that the best use of the HSV as a logistics resupply ship is as a rearming vessel for a CVBG or a DD(X) under wartime conditions. These HSVs might augment the CLF ships required in peacetime for this specific wartime need. Our investigation did not reveal a peacetime mission for these HSVs. [Ref. 12]

CNA's finding that HSVs are ineffective as wet product ships informs this thesis analysis, which will only study dry cargos for HSVs.

c. At-Sea Experimentation with Joint Venture, October 2001 through September 2002

The Navy Warfare Development Command (NWDC) asked CNA to help document the results of at-sea experimentation with JOINT VENTURE over a one-year period. The study focused on how the commercial technologies of the HSV might be useful for naval applications. Findings relevant to this thesis are included below:

- HSVs have sufficient range to shift quickly between theaters in an independent movement or to deploy with a CSG or ESG. In practice, such transfers will probably require that the ship carry minimal cargo.
- HSVs are competitive with air transport for intra-theater lift of ground units and their equipment.
- HSVs demonstrated efficient load and off-load of rolling stock, but slightly less efficient for containers, palletized break-bulk cargo, and helicopters. The loading process could be further engineered for speed.
- JOINT VENTURE demonstrated the ability to support daytime takeoff and landing of several SH-60 and CH-46 series helicopters. The helicopter deck was used to transfer passengers and to move small amounts of cargo. The lack of a helicopter refueling system and the need to move cargo to and from the flight deck by hand, limited the usefulness of JOINT VENTURE as a surrogate for testing HSV helicopter support concepts. [Note: Some of these issues are corrected in HSV 2 SWIFT]
- In a fully loaded condition, operations by JOINT VENTURE were unaffected in seas up to a significant wave height of approximately 8 feet. In higher seas, significant amounts of slamming occurred when JOINT VENTURE headed into the waves at speeds in excess of 10–15 knots. It is possible that a redesign of the ship could either mitigate the impact of slamming or produce a larger regime of unrestricted operations.
- HSVs demonstrated the ability to use austere ports with depths as shallow as 18 feet and restricted maneuvering room.
- JOINT VENTURE demonstrated the ability to conduct periodic operations at sea for periods of up to one week. Factors limiting the endurance of the test-bed ship include the ship's small crew size and a requirement to visit port to take on fuel or supplies, and maintenance requirements. [Ref. 13]

These findings indicate that while HSVs demonstrate some potential as logistics assets, some re-design and improvements are required to realize that potential. To that end, some limitations revealed by HSV-X1 are addressed in HSV 2 SWIFT or in the design for the 112m platform.

2. Naval Postgraduate School (NPS)

Two Naval Postgraduate School theses apply to HSVs and are summarized below:

a. *The Costs and Benefits of High-speed Vessels Relative to Traditional C-17 Military Airlift*

III MEF's anecdotal experience with WestPac Express is positive, but MSC requires solid analysis to backup any future procurement actions based on that experience. Thomas Strenge and Kevin Ralston developed their MBA Professional Report as a cost-benefit analysis for MSC to determine if the purchase or lease of more HSVs is warranted. In their analysis, they compare WestPac Express data to the closest alternative, Air Force C-17s. As mentioned above, given demonstrated capability to reduce airlift requirements significantly, the HSVs compare very well. Strenge and Ralston conclude that MSC should institutionalize HSV service within major theaters of operation and argue that reducing the procurement of Air Force C-17s by two aircraft would fund it sufficiently. Unfortunately, this analysis is completely cost-based and only compares HSVs to airlift. This study did not evaluate suitability and performance of the HSV relative to CLF and other sealift. [Ref. 8]

b. *Logistical Analysis of the Littoral Combat Ship*

The Navy is moving forward on the development of the Littoral Combat Ship (LCS), an affordable, small, multi-mission ship capable of independent, interdependent and integrated operations inside the littorals. The nature of the mission means that the LCS must incorporate endurance, speed, payload capacity, sea-keeping, shallow draft, and mission reconfigurability into a small ship design, a very problematic task. David Rudko analyzes the effect of speed, displacement and significant wave height on LCS fuel consumption and endurance and resulting impacts on LCS logistics. His study of the LCS is not directly related to this thesis, but he uses data from HSV-X1 JOINT VENTURE as a LCS surrogate, so some of the findings apply. His primary finding is that speed, displacement, and significant wave height all result in considerable increases in fuel consumption, and as a result, severely limit LCS (or HSV) endurance. The most relevant finding for this study is the importance of the iron triangle: the ship can achieve high-speeds, but only at the expense of range and payload capacity. This finding is an integral property of all HSVs and therefore a necessary characteristic of any model of them. [Ref. 14]

E. OBJECTIVES AND RESEARCH QUESTIONS

The primary objective of CTF73 is to provide better logistics support to its customers. In support of that objective, this thesis will quantify current levels of traditional logistics support and provide comparison to some HSV-based alternatives. It will determine whether addition of logistics support optimized HSVs to provide high-speed delivery of priority material, ordnance, and passengers significantly improves customer service levels for combatant ships in the 7th Fleet Theater of Operations. In the area of high-priority ordnance, this thesis will also explore the capabilities and performance of HSVs in the niche area of delivery of “low density” precision guided munitions (PGMs). During any large-scale conflict, operations will consume available stocks of PGMs within the theater very quickly. This requires shipment of PGMs from CONUS and a method to distribute them rapidly to the aircraft carriers for immediate use.

This thesis will also briefly address a secondary question concerning survivability and risk management in naval logistics. During the execution of the logistics support mission an HSV may be more survivable in a submarine-threat environment than existing CLF ships. While HSVs are not acoustically “stealthy” due to extensive engine noise and water jet propulsion, their high-speed makes the submarine pursuit and targeting problem very difficult. Addressing this issue in detail is outside the scope of this thesis. However, the analysis to answer the primary research question could provide a limited answer by quantifying the reduction of the more vulnerable large CLF ships’ shuttle cycle frequency gained by addition of HSVs in a CLF role.

F. SCOPE OF THESIS AND METHODOLOGY

A general simulation model of naval logistics support is required. This model is the Combat Logistics Force Scenario Analysis Tool (CLFSAT), a discrete event simulation (DES) that gives insight into performance of naval logistics in response to different peacetime and wartime scenarios. It serves as an exploratory tool to analyze force structure, levels, and employment and their resulting statistical effect on various measures of effectiveness (MOEs). For any individual scenario, CLFSAT will not and cannot predict the exact outcomes of real-world operations, but can compare the relative effectiveness of different courses of action.

To answer the specific research question, the simulation is focused on the 7th Fleet Theater and baseline COMLOGWESTPAC scenarios are implemented using traditional CLF assets. CLFSAT runs the scenarios and generates MOEs for evaluation. HSVs in a special CLF shuttle role are then added to the baseline scenarios and new MOEs are produced and evaluated as compared to the traditional CLF. CLFSAT does not explicitly model submarine threats, but reduction in CLF shuttle requirements should be apparent in the MOEs.

1. JAVA and Object-Oriented Programming

CLFSAT is implemented in the Java Programming Language, a freely available, object-oriented programming (OOP) language. Walter Savitch, in his textbook on the subject, describes OOP as follows:

> Object oriented programming is a programming methodology that views any program as a world consisting of objects that interact with each other by means of actions. An object is a program construction that has data associated with it and that can perform certain actions. When the program is run, the objects interact with one another in order to accomplish whatever the program was designed to do. The actions performed by objects are called methods. A class is a type or kind of object. All objects in the same class have the same kinds of data and the same methods. [Ref. 15]

OOP uses the principles of encapsulation, polymorphism, and inheritance to facilitate these interactions. The details of how objects work internally are hidden from the user (encapsulation) who only has to rely on a standard interface (polymorphism) to interact with a hierarchy of similar objects (inheritance). These OOP features make Java naturally suited to developing simulations because the Java code has an intuitive correspondence with the modeled reality. This makes simulation development relatively straightforward and reduces workload in the development process.

Potentially, the most important feature of Java for this application is its "portability". Java is platform independent, meaning the same code will run without modifications on Windows, Solaris, Linux, Macintosh, etc. It is also freely available, which means there are no license requirements to use it. This is critical if various commands intend to use CLFSAT as an analysis tool. There is no barrier to running the compiled tool on NMCI systems.

2. Simkit Discrete Event Simulations

Another advantage of Java, is it allows the use of Simkit, developed by Professor Arnold Buss at the Naval Postgraduate School. Simkit is a software package for implementing Discrete Event Simulation (DES) models in Java. DES relies on two fundamental elements: state variables, which are properties of objects, and events, which are objects performing actions, interacting, and changing state variables. A DES simulates the reality of a system by tracking the changes in these state variables over time, which can generate statistics for analysis of system performance. In order for time to progress and these events to occur, a DES requires a scheduling engine to govern the interactions. This engine is the Future Event List, a "to do" list of scheduled events. Unlike time-step simulations, time only moves forward in a DES when the next event on the Event List occurs. Nothing happens in between events. In this way, a DES is continually updating or changing the Event List and state variables based upon current events and time passed.

Simkit provides a pre-set component based structure for implementing a DES. It has implemented objects that move, sensors to detect them, and statistical packages to analyze their interactions. Through a structure of SimEventListeners, objects can listen for other objects to perform specific actions and then take corresponding actions. This allows objects to interact with each other without losing the advantages of OOP. Another structure called a PropertyChangeListener interfaces with the statistical routines to track changes in state variables over time. This allows the construction of robust simulations with every aspect of that simulation open to data collection and statistical analysis.

3. Global SeaRoutes Network

CLFSAT relies on the Global Sea Routes Network to represent the world and control how ships move through it. This network was developed over the span of three previous NPS theses by Kevin Borden, Ronaldo Givens, and John Cardillo supported by Distinguished Professor Gerald Brown and Associate Professor Matt Carlyle [Refs. 16, 17, & 18]. In these previous implementations, the network is implemented in the General Algebraic Modeling System (GAMS), which is particularly inefficient for that application, but facilitated their further optimization work within the same system. To function with CLFSAT, the Global SeaRoutes Network is re-implemented in Java.

The Global SeaRoutes Network is a model of the navigable world sea routes required for Navy ships to sail to, in and around traditional operations areas. The network consists of a set of nodes worldwide that are either at-sea waypoints or ports with logistics capabilities. Arcs are specified between adjacent node pairs to allow navigation between them on a great circle route or rhumb line route. Each arc carries a "cost" which is the rhumb line distance between the two nodes. Additionally, some arcs are "slow arcs" which force a limited transit speed. These represent natural chokepoints, straits, and canals, such as the Suez Canal or the Malacca Strait. Figure 9 presents the full network and Figure 10 presents a zoomed view of the area around Japan and Korea.

The Floyd-Warshall "all shortest paths" algorithm is applied to the Global SeaRoutes Network to generate the shortest paths between all nodes globally. When we use this resulting network for navigation, a ship at any point in the network can find and travel the shortest path to anywhere else in the network. Surprisingly, relatively few nodes are required to represent the majority of the world's naval operating areas. The algorithms are also flexible enough to handle any additions of desired nodes or arcs if new scenarios are required.

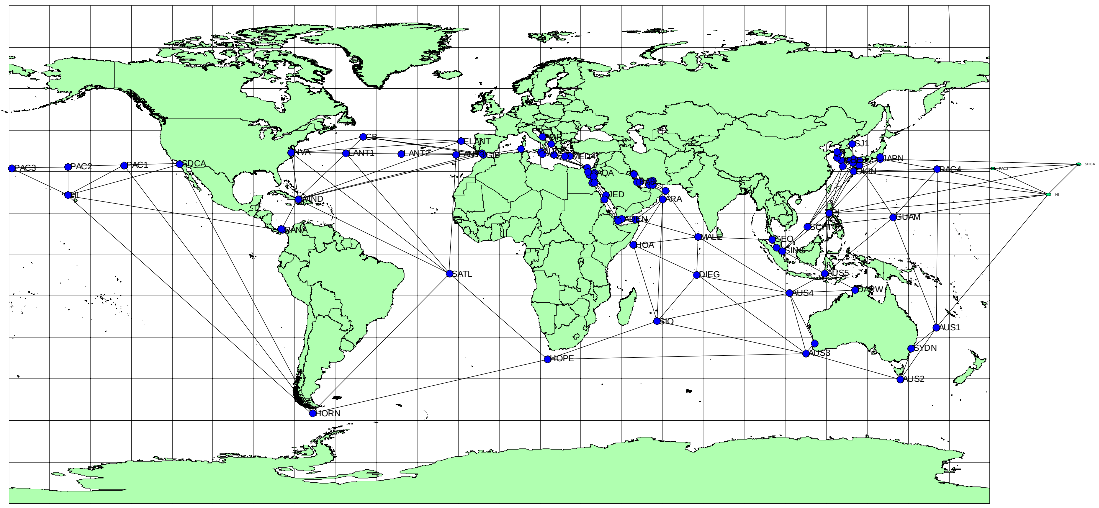

Figure 9. Global SeaRoutes Network with all nodes and arcs

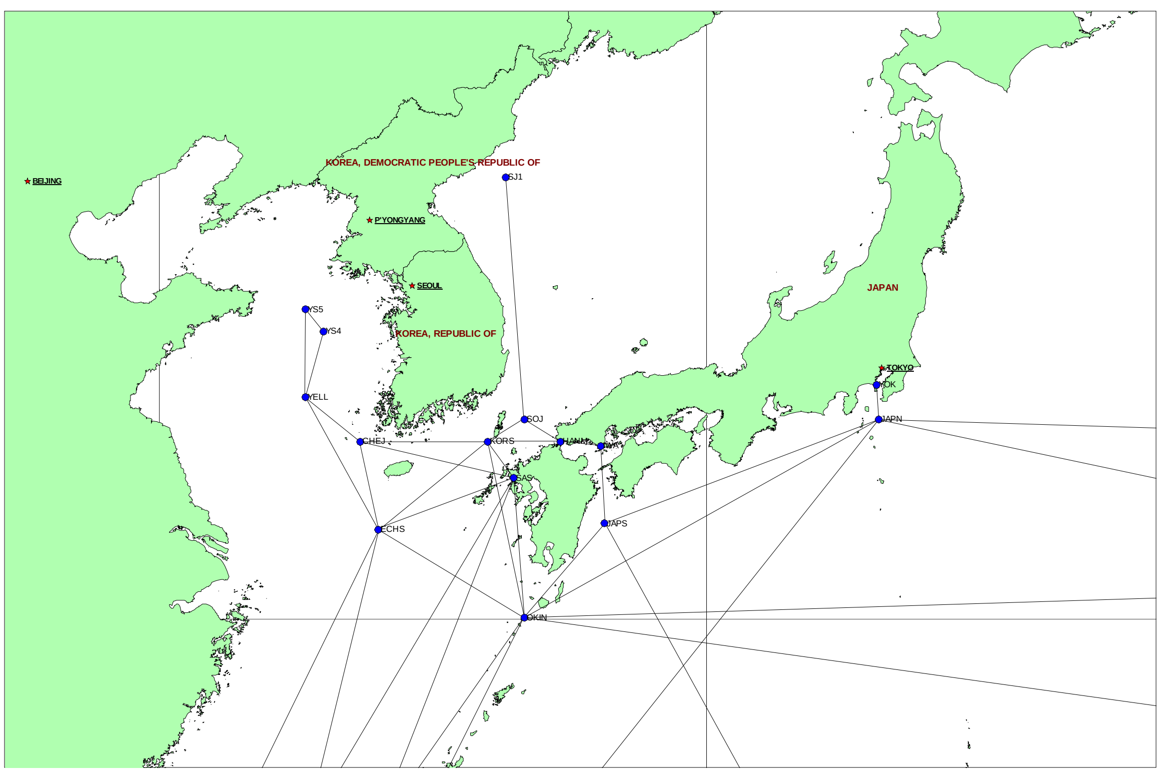

Figure 10. Global SeaRoutes Network around Japan and Korea

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III. THE CLF SCENARIO ANALYSIS TOOL (CLFSAT) AND IMPLEMENTED SCENARIOS

A. MODEL DESCRIPTION

The CLF Scenario Analysis Tool (CLFSAT) is a general tool that can answer naval logistics related questions for any area of the world under any desired scenario. This allows for potential reuse of the tool at the operational fleets (CTF53/63/73), Commander Fleet Forces Command, Chief of Naval Operations Staff (Navy Strategic Mobility and Combat Logistics - OPNAV N42), and the Combat Logistics Force Operational Advisory Group (CLF OAG) at Commander, Naval Surface Group, Pacific Northwest (COMNAVSURFGRU PACNORWEST). To support the Sea Power 21 vision, the model could be adapted to address Sea Basing issues that rely on some of the same core components as pure naval logistics. CLFSAT's ability to provide comparative performance measures between different courses of action and force levels also allows use as an OPLAN logistics-planning tool.

CLFSAT is a simulation involving "customer" ships that travel around the world or within a theater executing scripted actions in accordance with a specified scenario. The customer ships consume logistics commodities: Diesel Fuel Marine (DFM or F76), Aviation Fuel (JP5 or F44), ordnance, and stores. They also generate high priority requisition requirements through Casualty Reports (CASREPs) in accordance with historic rates. The consumption of these commodities creates requirements for replenishment based on established acceptable reserve levels. CLF ships, Carrier Onboard Delivery (COD) aircraft, and logistics ports dynamically satisfy these replenishment requirements. Statistics are collected throughout this process and are available for analysis at the end of the simulation run.

B. MODEL COMPONENTS

CLFSAT is composed of an Executive controller and three main components: the Database, the Global SeaRoutes Network, and the Simulation. The Executive uses information from the Database to coordinate the building and linking of objects, sets run parameters, sets up statistics collection, starts the Simulation, and controls output. It merely sets the scene for the simulation and provides a central location to allow easy editing of desired parameters. A separate Statistics component receives statistical observations from the Simulation objects and then outputs them at the end of the run. Figure 11 presents the general structure of CLFSAT and shows the flow of information between the four components.

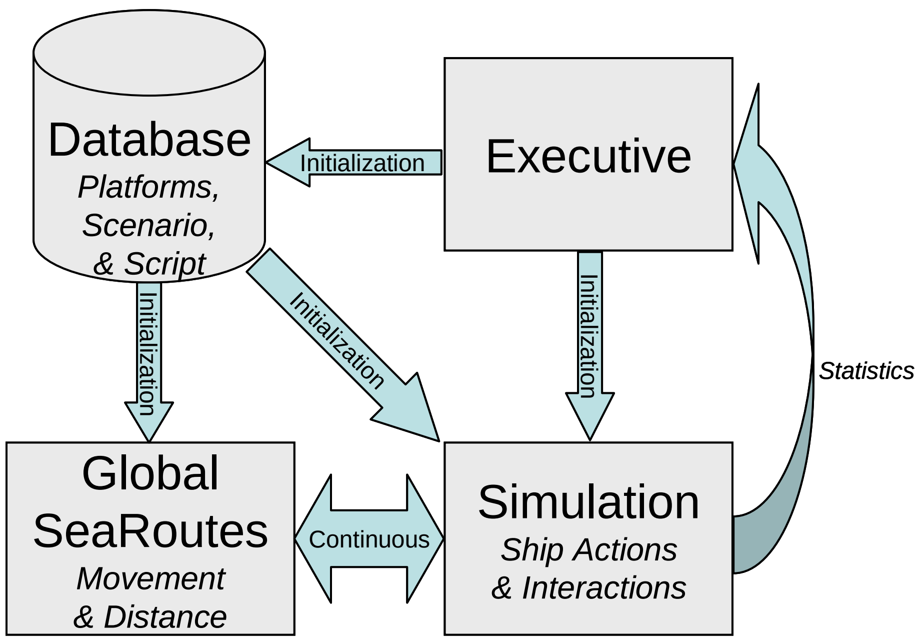

Figure 11. CLFSAT Structure and Flow

1. Database

The Database is the primary interface for the user of CLFSAT. It is a Microsoft Access database and contains seven tables that provide static information for the functioning of the simulation and three tables that allow the user to implement the desired scenario. The Network class of the Java Simkit simulation is responsible for opening this database and using the table information to create lists containing the Java structures for all the Global SeaRoutes network. The DataBaseInfo class then opens this database and uses the table information to create lists containing the Java structures for all customer ships, CLF ships, PGMs, and ports. The Network and DataBaseInfo classes maintain these lists for access by other parts of CLFSAT.

The following paragraphs present specific details of each table in the Access database:

a. CustomerData

This table contains data for customer ships keyed by the class name. The table specifies maximum speed in knots, commodity capacities and use rates for DFM, JP5, ordnance, and stores, and fuel and dry replenishment transfer rates. Also included is the historical CASREP rate for that class. The reciprocal of this rate represents the mean inter-arrival time for a Poisson Process in hours.

b. CLFData

This table contains data for Combat Logistics Force (CLF) ships, both station and shuttle, keyed by the class name. The table specifies maximum speed in knots, own-ship DFM capacity and use rate, cargo capacities for DFM, JP5, ordnance, and stores, as well as fuel and dry replenishment transfer rates.

c. Ports

This table contains data for logistics ports keyed by an abbreviated name identifier. The table specifies a description of the port (long name), port loading capacities for fuel and dry stores (in numbers of ships), cargo capacities for DFM, JP5, ordnance, and stores, as well as fuel and dry replenishment transfer rates. These capacities are currently dummy values, as the simulation does not currently handle the strategic resupply of logistics commodities to ports.

d. PGMs

This table contains data for Precision Guided Munitions (PGMs). The table specifies a name, shipping weight (in short tons), standard quantity loadouts for carriers and CLF station ships and the quantity allowed in an air shipment.

e. RRTs2004

This table contains Requisition Response Times (RRTs) for all Pacific Fleet CASREP Whiskey Requisitions that were processed in 2004 [Ref. 23]. CLFSAT samples RRTs from these values.

f. SeaRoutes_Nodes

This table contains data for the nodes in the Global Sea Routes Network keyed by an abbreviated name identifier. The table specifies the latitude-longitude pair indicating the location of the node and a description of the node (long name). Latitude is positive in the Northern Hemisphere and negative in the Southern. Longitude is positive East of the Prime Meridian, and negative to the West.

g. SeaRoutes_Arcs

This table contains data for the arcs between nodes in the Global Sea Routes Network keyed by the abbreviated name identifiers of the tail and head nodes. The table also specifies the maximum transit speed allowed for restricted maneuvering arcs, usually international straits and canals.

h. CustomerShips

This table is user-specified and contains data for the actual customer ships included in the specific simulation scenario. The table specifies the name of the ship, hull number, class, starting latitude and longitude, and if assigned, the station ship's name. This table must contain every customer ship intended to be included in the simulation.

i. CLFShips

This table is user-specified and contains data for the actual CLF ships included in the specific simulation scenario. The table specifies the name of the ship, hull number, class, starting latitude and longitude, a flag to determine if it is a station ship, and the name identifier of the assigned base port if it is a shuttle ship. This table must contain every CLF ship intended to be included in the simulation.

j. ShipTasks

This table is user-specified and contains supporting data for the scripted actions of customer and CLF station ships in the specific simulation scenario. Each entry in the table specifies the name of the ship, the start and end times for the action, the latitude and longitude of the action, a flag to indicate if the task is a move order, and a flag to indicate if the task is to expend ordnance. Movement orders are a destination and a no-later-than time for arrival at that destination, and as such, should require a feasible speed for completion. The entries should be in chronological order by start time for any given ship.

2. Global SeaRoutes Network

This component is responsible for representing the navigable world as described in Chapter 2. It is implemented in Java as the seaRoutes package. This package is composed of four classes: GeoCoord, Node, Arc, and Network. In addition to providing the structure upon which simulation objects navigate, it acts as the bridge between the scenario's geographic world based on latitude and longitude and the simulation's Cartesian world based on x and y coordinates.

a. GeoCoord

This class implements a geographic coordinate in latitude and longitude for use by SeaRoutes network and the rest of the simulation. Latitude is measured from the equator, with positive values going north and negative values going south. Longitude is measured from the Prime Meridian (which is the longitude that runs through Greenwich, England), with positive values going east and negative values going west.

The class works internally in radians, but can take input and provide output in degrees. Algorithms are available to calculate the rhumb line distance or bearing between any two coordinates. These algorithms also form the basis for the geographic to Cartesian translation. The intersection of the Prime Meridan (y-axis) and the Equator (x-axis) is considered the Cartesian (Point2D) origin point, with x and y values calculated by rhumb line distance along the respective axes. This method introduces some minor differences in distance between any two points, but these differences are consistent throughout the simulation and thus exhibit little impact.

b. Node

This class implements the basic node in the SeaRoutes network. It has a name, locations in geographic and Cartesian space, and if there is a port located at the node, may have a port object assigned to it. It also maintains the data structures required to keep the shortest paths information calculated by a Floyd-Warshall all shortest paths algorithm. By definition, once initialized by the algorithm, any node "knows" the shortest path and associated shortest distance to any other node.

c. Arc

This class implements the basic arc in the SeaRoutes network. It has a name, tail and head nodes, a cost (distance), a maximum allowed transit speed, and a flag to indicate if the arc is restricted maneuverability.

d. Network

This class builds and maintains the SeaRoutes network consisting of purely nodes and arcs. Like DataBaseInfo, it reads nodes and arcs in from CLFSAT DataBase and builds the internal data structures to represent the network. Once the network is complete, this class performs the Floyd-Warshall all-shortest paths algorithm to build distance lookups and create the shortest path predecessor structure for all of the child nodes. It provides an algorithm to calculate a global distance in the Cartesian grid that accounts for the wrap around at the International Date Line. It also can find the closest node to any given location and return the shortest path transit distance between any two Cartesian locations.

3. Simulation (smdx)

This component provides the objects required to run the actual Simkit simulation. As such, most Java classes within this smdx package are extensions of Simkit classes and all rely on Simkit routines to manage events and timing. The package includes classes to implement all simulation objects, managers to control them, and protocols to communicate between them. Specifics of each class are included below.

a. Ship

This class implements a basic Ship object. It is an extension of a Simkit UniformLinearMover, but reinterprets all of the movement routines to work within the Cartesian interpretation of the geographic world used by the Global SeaRoutes Network. It has a name, class, maximum speed, own-ship DFM capacity, current level and use rate, fuel and dry replenishment transfer rates, a schedule, and keeps track of its own requests for fuel, ordnance, or stores replenishments. It also keeps track of the last update time for logistics levels, a critical requirement in a discrete event simulation that always needs to know how much time has passed to accurately track dynamic values. Ships have methods to control simple linear movement (straight-line, set-speed, no obstacles), update logistics levels, request replenishment, and control execution of a scripted schedule. The Ship class is the core building block for the more specific types of Ships discussed below.

b. Customer

This class extends the Ship class to implement a customer ship, which is any combatant or non-combatant ship that is a generator of logistics requirements. It has all the properties of the Ship class and adds own-ship capacities, current levels and use rates for the three remaining commodities: JP5, ordnance, and stores. A customer tracks whether or not it is currently expending ordnance, and knows which CLF station ship it is assigned to, if any. It also maintains its own Poisson Process to control “arrivals” of Casualty Reports (CASREPs) and then maintains a list of them until CLFSAT fills the associated high-priority parts requirements. Customers are able to update logistics levels, calculate future requirements for replenishment, schedule and cancel planned replenishments, and control execution of the actual Underway or Inport Replenishments (UNREPs or INREPs).

c. Carrier

This class extends the Customer class to implement the specific routines for an aircraft carrier. It has all the properties of the Customer class and adds the ability to generate a random number of air sorties on a daily basis. This generated number of sorties controls ordnance and JP5 consumption. Carriers also maintain magazines of Precision Guided Munitions (PGMs).

d. CLF

This class extends the Ship class to implement the general routines for any CLF ship, which is any ship that is a provider of logistics commodities to customer ships. It has all the properties of the Ship class and adds cargo capacities and current levels for the all commodities: DFM, JP5, ordnance, and stores. They maintain lists of CASREP related high-priority parts and PGMs currently staged onboard for delivery to customers. CLF ships know whether they are station ships and whether they are oilers, ammo ships, or stores replenishment ships. If assigned as shuttle ships, they also know their assigned base port. CLF ships are able to update logistics levels and control execution of the actual UNREPs or INREPs. The CLF class is the core building block for the Shuttle and CLF station ships discussed below.

e. ShuttleCLF

This class extends the CLF ship class to implement the specific routines for a CLF ship acting in a shuttle role. These ships cycle between base ports and customer ships or CLF station ships to provide at-sea logistics replenishment. Shuttle CLF does not add any properties to the CLF class, but does handle slightly different events. CLF shuttle ships are able to evaluate planned replenishments and schedule their next INREP for reloading, schedule and cancel planned replenishments, and control execution of Consolidations (CONSOLs) with CLF station ships.

f. StationCLF

This class extends the CLF ship class to implement the specific routines for a CLF ship acting in a station ship role. These ships operate with Carrier Strike Groups (CSGs) to provide at-sea logistics replenishment for all assigned customer ships. A CLF station ship has all the properties of the CLF class, but also keeps a queue of scheduled replenishments. CLF station ships are able to evaluate planned replenishments and request CONSOLs from a shuttle ship as required, schedule and cancel planned replenishments, and control execution of CONSOLs with CLF shuttle ships. These ships combine aspects of CLF shuttle ships with aspects of customer ships to enable proper functioning in both roles.

g. HSV

This class extends the CLF ship class to implement the specific routines for HSVs acting in a shuttle role. These ships cycle at high-speed between base ports and customer ships or station ships with small loads of CASREP related parts, PGMs, and with any excess capacity filled with generic ordnance and stores. HSVs keep a list of assigned customer ships and know which of those are within range at all times. They are responsible for their own scheduling based on availability of appropriate cargo and range to assigned customers. When loads are available, HSVs load the material, depart port, transit directly to their assigned customers operating area, transfer required material, visit any other assigned customers that are close enough, and then return to port immediately to refuel and await another load. When CASREP parts or PGM loads are not available, the HSV remains in port for default time, currently 48.0 hours, loads general ordnance and stores only, then departs to service assigned customers.

h. Port

This class implements a port object. It has a name, port loading capacities for fuel and dry stores (in numbers of ships), cargo capacities and levels for DFM, JP5, ordnance, and stores, fuel and dry replenishment transfer rates, and maintains a list of CASREP related high-priority parts currently staged at the port for delivery to customers. It also keeps track of shuttle ships assigned there as a base port and it links to its node location in the Global SeaRoutes Network. Ports are able to handle execution of INREPs. Routines to handle strategic resupply and dynamic variation of port logistics levels are not implemented and represent an area for expansion of the simulation.

i. ShipTask

This class implements a single task object that is used to populate a ship's schedule with scripted and dynamic tasks. It is the structure used to hold the scenario-driven scripted events read from the Database ShipTasks table. It has a start and end time for the task, the location (Cartesian) of the task, flags to indicate if the task is a move order, UNREP, INREP, CONSOL, or expenditure of ordnance, and for replenishment tasks, a reference to the appropriate ReplenishmentRequest.

j. ReplenishmentRequest

This class represents the communications protocol by which a customer or CLF station ship requests replenishment from a CLF shuttle ship. It has a reference to the requesting customer ship, the expected location and time of the replenishment, the assigned CLF (shuttle or station) ship for an UNREP or CONSOL, the assigned port for an INREP, flags to indicate whether the request is for fuel, ordnance, or stores, and a flag to indicate if the request has been scheduled for execution.

k. CasualtyReport

This class represents the communications protocol by which a customer tells the world that it has a failure of a critical piece of equipment requiring high priority routing of repair parts to that customer. CASREPs in the CLFSAT represent only those requiring high priority parts to correct. Each CASREP has a reference to the requesting customer ship, a ship-specific serial number, the date-time-group of the report, and a flag to indicate whether this emergency requisition has been filled.

l. PGM

This class represents a single example of a precision guided munition (PGM), e.g. an AGM154 Joint Standoff Weapon (JSOW). It has a name, shipping weight and sortie use rate. It also has standard quantity loadouts for carriers and CLF station ships and the quantity allowed in an air shipment.

m. PGMs

This class represents a shipment of multiple precision guided munitions (PGMs). It has a name (the same as the single PGM), a reference to the single PGM, a quantity, and a total shipment weight. It also tracks the time the shipment was available in theater to allow statistical analysis for MOEs.

n. ReplenishmentManager

This class performs as an executive agent to maintain, assign, and prioritize replenishment requests and replenishment events for all customer and CLF ships. It is an attempt to best replicate within the simulation the methods by which COMLOGWESTPAC (CTF 73) performs this role in the real world. The Replenishment Manager maintains references to all ships and ports in the simulation, lists of all replenishments and CASREPs, and helps to generate statistics for those replenishments.

The Replenishment Manager controls assignment of each customer Replenishment Request to either a CLF ship or INREP. This assignment initially defaults to any assigned station ship. If no station ship is assigned, the Replenishment Manager iteratively queries each CLF shuttle ship assigned to the closest Forward Logistics Site (FLS) to determine if it can add the requested replenishment to its schedule. The CLF shuttle finds the appropriate place in its schedule where the new replenishment must occur and determines if it can still feasibly accomplish all currently scheduled replenishments and the new one. If the CLF shuttle finds the new replenishment is feasible, it adds it to its own schedule, informs the customer that the event is scheduled, and reports to the Replenishment Manager that it successfully scheduled the replenishment. If none of these shuttle ships can service the replenishment request, the

Replenishment Manager directs the customer ship to break off operations, and proceed to the closest logistics port for INREP. The Replenishment Manager is also responsible for receiving and filling CASREP requisitions then directing the resulting high priority material to COD delivery if in range, and if not, staging it at the FLS for CLF shuttle delivery.

o. SeaRouteMoverManager

This class acts as a manager that allows a Ship to navigate along the Global SeaRoutes Network from one location to another. The Ship itself is only responsible for simple linear movement in a world with no obstructions and a set speed. The mover manager controls long distance, waypoint based routing using the Global SeaRoutes Network by breaking these into simple linear movements for the Ship to execute. It interprets movement order ShipTasks from the Ship's schedule and controls their execution. The mover manager maintains a reference to the Ship it controls, a list of waypoints and the Ship's place in them, the location (Cartesian) of the destination, the expected arrival time, the current speed, and a reference to the network it is moving on. It is also capable of calculating the future projected position for a Ship given a time.

p. ArrivalProcess

This class implements a random arrival process given passed parameters and the inter-arrival time distribution. This allows it to schedule arrivals for any desired distribution. The Customer class uses this class to implement CASREP arrivals. It is capable of delaying the start of the process until some desired future time in the simulation.

4. Statistics

This component is responsible for collecting statistical observations from the simulation and placing them in a data structure. It does not specify which statistics to collect or how they should be organized, but processes and stores any numerical statistics sent to it. Individual observations specify an *owner* (whose number it is), a *type* of statistic (the name of the statistic to be tracked), a *time* stamp, and a *value*. Succeeding observations are associated with previous observations by *owner* and *type*. When the simulation is complete, statistics can be output to an Excel spreadsheet workbook. In that workbook, each *owner* gets a separate sheet, with each *type* of statistic organized in columns with *time* and *value* pairs.

C. ASSUMPTIONS & DATA SETS

1. Force Structure and Availability

Only U.S. Navy forces available in 2005 are used. The force structure used for analysis in the simulation is based on the Fleet Response Plan which permits deployment of 6 Carrier Strike Groups (CSGs) within thirty days and an additional two CSGs within 60 days after that. Forward Deployed Naval Forces (FDNF), as well as 3^{rd} and 7^{th} Fleets, provide additional forces. Combat Logistics Force ships typically assigned to CTF73 are available to service replenishment requests. CLFSAT does not implement submarines due to limited logistics support requirements.

a. Carrier Strike Groups (CSGs)

CSGs are assumed to consist of one Aircraft Carrier (CV or CVN), two Guided Missile Cruisers (CG 52), two Guided Missile Destroyers (DDG 51 or 79), one Guided Missile Frigate (FFG 7), and one Fast Combat Support Ship (T-AOE) acting as the CLF station ship. Actual composition of CSGs does vary from this core design based on combatant availability. Some CSGs will also substitute an Oiler (T-AO)/Ammunition Ship (T-AE or T-AKE) pair for the T-AOE.

b. Expeditionary Strike Groups (ESGs)

ESGs are assumed to consist of one Amphibious Assault Ship (LHA or LHD), one Amphibious Transport, Dock (LPD 4), one Landing Ship, Dock (LSD 41 or 49), one Guided Missile Cruiser (CG 52), one Guided Missile Destroyer (DDG 51 or 79), and one Guided Missile Frigate (FFG 7). ESGs are not assigned CLF station ships and are reliant on CLF shuttle ships for sustainment.

c. Surface Strike Groups (SSGs)

Though not as common as CSGs or ESGs, Surface Strike Groups (SSGs) are still a legitimate deployment construct, especially with FDNF, Japan. SSGs perform strike missions and theater ballistic missile defense. A typical SSG consists of one Guided Missile Cruiser (CG 52), and two Guided Missile Destroyers (DDG 51 or 79).

d. Combat Logistics Force (CLF) Ships

There are several CLF Shuttle ships assigned to COMLOGWESTPAC for tasking in 7th Fleet. One of the T-AOs could be unavailable while deployed to 5th Fleet or undergoing required maintenance after that deployment. The rest are assumed available, with the potential to draw CLF from other fleets in a large MCO scenario. The shuttle ships tend to operate from three main base ports, Sasebo in Japan, Guam, and Singapore. Table 3 lists the CLF Shuttle ships assigned to COMLOGWESTPAC in June 2004. The particular ships assigned may change over time, but the numbers generally remain the same.

Fuel	Ordnance	Stores
USNS Guadalupe (T-AO 200)	USNS Kiska (T-AE 35)	USNS Concord (T-AFS 5)
USNS Yukon (T-AO 202)	USNS Shasta (T-AE 33)	USNS San Jose (T-AFS 7)
USNS John Ericsson (T-AO 194)		USNS Niagara Falls (T-AFS 3)
USNS Tippecanoe (T-AO 199)		

Table 3. CLF Shuttle Ships Assigned to COMLOGWESTPAC, June 2004

2. Replenishment Planning Cycle

Planning for logistics replenishments is typically governed by tracking a ship's percentages of commodities remaining and requiring replenishments when those percentages reach a pre-defined reserve level. In the most common case, a customer ship is part of a CSG, with an assigned multi-product CLF station ship. When a customer's current level in any commodity falls to 50 percent of the total storage capacity for that commodity, an underway replenishment (UNREP) is called for from the CLF station ship. In turn, when the CLF station ship's current level in any commodity falls to 30 percent of the total storage capacity for that commodity, a consolidation (CONSOL) for that commodity is called for from a single-product CLF shuttle ship. These CLF shuttle ships essentially cycle continuously between the CLF station ship and logistics resupply ports. Figure 12 illustrates this most typical replenishment cycle. Since ESGs are not assigned CLF station ships, UNREP requests are usually handled by the Amphibious Assault Ship (LHA or LHD) or CLF shuttle ships directly. CLF shuttle ships must handle ships in SSGs or independent steaming directly or they are forced to INREP.

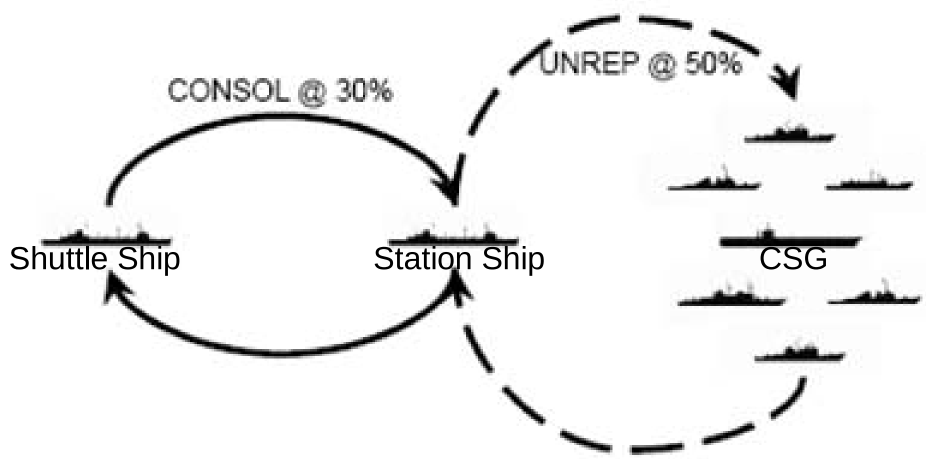

Figure 12. CONSOL and UNREP Cycle

3. Commodities Consumption and Logistics Planning Factors

In order to plan future logistics support for naval forces, it is necessary to forecast the logistics requirements of those forces. This is nearly impossible without a set of pre-defined, fixed usage factors. These are referred to as Logistics Planning Factors (LPFs) and are used extensively by all of the services. In naval logistics, these LPFs are usually expressed as a rate per time usage, e.g. barrels of fuel per day, or inversely, as "Days of Supply." There are, unfortunately, fundamental inaccuracies caused by using LPFs. Based on average values, LPFs fail to capture variations in activity levels and only represent accurate values over the long run. As the granularity of the time period is increased, LPFs can look increasingly inaccurate. Despite these problems, LPFs are one of the only feasible methods for quickly forecasting logistics requirements, thus are relied upon quite heavily in both planning logistics support and modeling logistics processes.

Historically, the Navy has had difficulties defining a single, durable set of accurate LPFs. These LPFs remain accurate only as long as their base data set remains a relevant representation of current naval operations. For Operation Desert Storm (ODS) in 1991, the Navy still used ordnance LPFs based on Vietnam War usage rates, which were fundamentally inaccurate after 20 years of aircraft and precision-guided munitions (PGMs) advancements. Unfortunately, ordnance LPFs revised to reflect the reality of ODS strike operations were equally inaccurate when applied to OEF in 2001 and OIF in 2003. Ten more years of advancements in PGMs, threw all predictions of tons of ordnance per sortie and sorties per day out the window.

Recently, OPNAV N42 standardized naval LPFs and logistics capacity data for Navy ships. The fundamental inability to compare the results of studies and analysis that used differing LPFs and capacities drove this standardization effort. Standardization allows all analysis and planning to start with a common set of assumptions and increases the ability to compare and analyze alternatives. N42 collected the different LPFs and capacity numbers used throughout the Navy, categorized and normalized them, then selected the ones that best represent current naval operations. The complete set of these planning factors was approved in July 2004. [Ref. 19]

Many CLF analysis models, especially the Borden, Givens, and Cardillo optimization models mentioned earlier [Refs. 16, 17, and 18] use these LPFs to represent actual consumption in their model. This reliance on "average" values creates potential inaccuracies in their results. Fortunately, CLFSAT is a simulation, not a highly abstracted optimization model of naval logistics. This allows CLFSAT to use these standardized LPFs only for forecasting and replenishment planning, while it models actual consumption of some commodities with higher fidelity, such as using actual speed and fuel consumption regression equations to model fuel usage as detailed below.

a. Diesel Fuel Marine (DFM)

DFM is ship's propulsion fuel and ship class, propulsion plant configuration, and speed drive consumption. N42's planning factors for DFM have two levels, surge (high-speed) and sustain (cruising speed), and are expressed in barrels consumed per day. These planning factors are sufficient for planning purposes, but inaccurate for a simulation that needs to determine actual fuel consumption over short time periods. A study on predicting ship fuel consumption by Schrady, Smyth, and Vassian [Ref. 21] provides a more accurate option. The study performed regression analysis on ship class fuel consumption trials data to develop predictive equations for fuel consumption per hour dependent on speed. CLFSAT uses these equations to control actual consumption of DFM by each ship. Using the class-specific coefficients in Table 4, the fuel consumption equation is:

$$F = p_o + p_1 e^{p_2 v^3}$$

F is fuel consumption (gal./hr)

v is ship speed in knots

p_0, p_1, p_2 are coefficients specific to ship-class

Ship Class	p0	p1	p2
CV-63/67	10865.9000	-8937.6000	32.6666
CG-52	2215.3900	-1429.0400	37.4831
DDG-51/79	1379.6200	-764.4330	51.5925
FFG-7	951.1170	-545.7160	51.8843
LHA-1	6530.1500	-5577.6800	39.3264
LHD-1	2039.4100	-700.8110	78.209
LPD-4	1566.7900	-1124.4300	95.4647
LSD-41	32693.5000	-32454.8000	2.8619
T-AOE 6	-12232.3000	12117.2000	-25.7866
T-AO 187	-4614.8100	4834.5400	-44.9642
T-AE 26	-16150.3000	16343.7000	-8.8660
T-AFS-1	1727.4600	-1471.6600	55.5118

Table 4. DFM Consumption Equation Coefficients by Ship Class [After Ref. 21]

b. Aviation Fuel (JP5)

JP5 is aviation fuel used by aircraft on the carrier and helicopters on the smaller combatants. JP5 usage is OPTEMPO driven. For the smaller combatants, JP5 is only used by their organic helicopter assets, which fly limited hours per day. This makes use of a JP5 planning factor reasonable. For aircraft carriers, JP5 varies extensively based on the number of sorties flown per day. The number of sorties per day varies based on operations plans, ordnance resupply, and operational availability of the aircraft. A 1992 NPS study titled "Carrier Air Wing Sortie Rates and Fuel Use" [Ref. 22] examined this issue and found that the variation in number of sorties takes the form of a normal distribution. The study examined two carriers in both an exercise and ODS and developed the normal means and variances for the four situations. For active combat operations, CLFSAT uses the average of the four different situations, with a mean of 100 sorties and a standard deviation of 15. The minimum level of air activity experienced during transits is derived from N42's sustainment LPFs and represented by 57 daily sorties.

The study further found that once the number of sorties for the day is determined, a simple regression equation provides daily JP5 usage for the airwing:

$$JP5(kgal) = -6.11 + 2.31 * Sorties$$

Converting this consumption to barrels yields:

$$JP5(bbls) = -145.48 + 55 * Sorties$$

c. Ordnance

Ordnance consumption is also dependent on operations and is more complex than any other commodity. For the smaller combatants, the number of submarine prosecutions, air raids defended against, enemy surface ships engaged, and strike and Naval Surface Fire Support (NSFS) missions fired drives ordnance consumption. In some cases, this ordnance is not replenishable at sea (e.g., Tomahawks), so the consumption is irrelevant for logistics resupply purposes. For aircraft carriers, the number of defensive sorties and strike sorties flown drives the consumption. Rough analysis of ODS, OEF and OIF data indicate that an average value of 1.5 short tons per sortie is reasonable.

d. Stores

Stores consist of Class I Subsistence, Class VI Personal Demand Items, and Class IX Repair Parts. They are the one commodity that appears not to vary based on the activity of the ship. Consumption of stores stays constant as long as number of personnel onboard stays constant. This only becomes an issue for amphibious ships that offload their embarked Marines. Due to this constancy, stores consumption behaves very much like a LPF. The N42 LPF [Ref. 19] for stores consumption per day by ship class is used in CLFSAT and is presented below in Table 5.

Ship Class	Stores Consumption (stons/day)
CVN-68	28.4
CV-63/67	28.4
CG-52	1.87
DDG-51/79	1.82
FFG-7	1.14
LHA-1	14.87
LHD-1	14.87
LPD-4	5.31
LSD-41	3.98

Table 5. Stores Consumption LPF by Ship Class [After Ref. 19]

4. Ship Logistics Capacities

When N42 standardized planning factors, they also standardized the commodity capacities for each ship class [Ref. 19]. These numbers reflect actual usable and transferable capacities that take into account ship design restrictions and stability issues. The carriers normally reserve a significant portion of the listed JP5 capacity (up to 12,000 bbl) for transfer to small combatants in their CSG. For the new T-AKE, the Ordnance and Stores capacities are reconfigurable and entries represent the standard configuration. Table 6 presents the standardized capacities.

Ship Class	Own DFM (bbls)	Cargo DFM (bbls)	JP5 (bbls)	Ordnance (stons)	Stores (stons)
CVN-68	0	0	74642	1765	1710
CV-63/67	54283	0	45124	1765	1247
CG-52	15032	0	475	94	68
DDG-51/79	10518	0	475	48	55
FFG-7	4286	0	475	16	35
LHA-1	45125	0	10450	391	520
LHD-1	42976	0	9952	391	520
LPD-4	17700	0	443	88	195
LSD-41	19150	0	1144	38	140
T-AOE 6	30000	52770	42036	2593	1111
T-AO 187	12357	72000	56873	0	220
T-AE 26	12350	5634	0	4928	0
T-AFS-1	12350	5634	0	0	4518
T-AKE	12357	18000	8000	4700*	1180*
T-HSV	Varies	0	475	Varies	Varies

Table 6. Ship Commodity Capacities [After Ref. 19]

5. Ship Replenishment Transfer Rates

N42 also standardized transfer rates for at-sea replenishment [Ref. 19] These are specified as maximum "give rates" for CLF ships and maximum "receive" rates for customer ships. Dry transfer rates are a combination of connected replenishment (CONREP) and vertical replenishment (VERTREP), except for the T-HSV which is VERTREP only. Table 7 presents the transfer rates.

Ship Class	Fuel Transfer (bbls/hr)	Dry Transfer (stons/hr)
CVN-65/68	21420	271
CV-63/67	12855	271
CG-52, DDG-51/79, FFG-7	8568	135
LHA-1/LHD-1	8568	271
LPD-4	4285	135
LSD-41	8568	135
T-AOE 6	21420	271
T-AO 187	21420	100
T-AE 26	0	271
T-AFS-1	4285	271
T-AKE	4285	271
T-HSV	0	130

Table 7. Replenishment Transfer Rates [After Ref. 19]

6. Casualty Report Frequencies

Arrivals of CASREPs are assumed to follow a Poisson Process with corresponding inter-arrival times that are exponentially distributed. The parameter most commonly used to define the Poisson Process is λ, used to represent the rate of the process. When inverted to 1/ λ, this represents the expected value or mean of the exponential inter-arrival times. This means, that on average, there are 1/ λ time units between arrivals, so the arrivals come at an average rate of λ per unit time. To most accurately represent the CASREP arrival process, the rate should be derived from actual data. The following provides an unbiased estimator of 1/ λ [Ref. 20]:

X_i is the i-th inter-arrival time

$T_k = X_1 + X_2 + ... + X_k$ is the sum of the first k inter-arrival times

$\mathrm{E}(\frac{\mathrm{T_k}}{\mathrm{k}}) = \frac{1}{\lambda}$ therefore $\frac{\mathrm{T_k}}{\mathrm{k}}$ is an unbiased estimator for $\frac{1}{\lambda}$

The U.S. Navy Priority Material Office provided a database containing all CASREP-related (Whiskey) requisitions for Pacific Fleet surface force ships for the last five years [Ref. 23]. Commander, Naval Air Forces provided similar data for carriers and their associated air wings [Ref. 24]. The data for each ship is segregated and used to calculate actual inter-arrival times, then the unbiased estimator, T_k/k, is used to calculate the mean inter-arrival time for that ship. These ship-specific means are averaged for all ships in a class to establish class-specific CASREP mean inter-arrival times. Individual ship means can be skewed by deployments and maintenance periods. Using five years of data will tend to smooth this out and aggregating to class-specific means will smooth these variations out. Table 8 specifies these values as mean hours between arrivals.

Ship Class	CASREP Inter-Arrival Time Mean (Hours)
CV-63/67	21
CVN-65	34
CVN-68	59
CG-52	120
DDG-51	149
DDG-79	283
FFG-7	169
LHA-1	110
LHD-1	78
LPD-4	228
LSD-41	160

Table 8. CASREP Mean Inter-Arrival Times by Ship Class [After Ref. 23 & 24]

7. Precision Guided Munitions (PGMs)

For some scenarios, PGMs are in short supply. There is a small quantity available on each carrier, and one full carrier resupply quantity available on each CLF station ship. The rest of the PGM inventory is stored in CONUS, not in theater munitions stockpiles. Combat operations consume available stocks of PGMs within the theater very quickly, requiring shipment of additional PGMs from CONUS via a T-AE, T-AKE, or MSC sealift ship. Activating this ship, sending it to load at a Weapons Station, transiting to the theater and then offloading to theater munitions stockpiles could take weeks. During this delay, the Navy must supply PGMs to the theater by other means. The only method faster than sealift is airlift by military transport. The quantity of airlifted PGMs is limited by their explosive potential, so this method is not capable of providing a massive throughput of weapons. Airlift serves to "fill the gap" while sealift delivers the bulk of the PGMs. For each of the PGMs, CLFSAT requires weight and appropriate loadout data. Public domain sources provide much of the data [Ref. 25 & 26]; the rest is notional data that does not influence the MOEs of CLFSAT, and which can easily be replaced by real data if available. The Air Shipment Load Data is also notional and sized to allow a complete shipment of all six PGMs in specified quantities to weigh less than half of the full cargo capacity for one C-17, and to limit Net Explosive Weight totals for the shipment. Table 9 details these notional, unclassified numbers for the specific PGMs implemented.

PGM	Shipping Weight (stons)	Carrier Load	CLF Station Load	Air Shipment Load
AGM-154 JSOW	0.6	10	10	10
AGM-158 JASSM	1.13	10	10	5
AIM-120 AMRAAM	0.17	300	300	50
KMU-556 JDAM Kit	0.075	50	50	100
KMU-558 JDAM Kit	0.1	100	100	100
KMU-559 JDAM Kit	0.05	200	200	100

Table 9. Precision Guided Munitions (PGMs), Notional Data [After Ref. 25 & 26]

8. HSV Characteristics

Incat 112M High-speed Support Ship (HSSS) and the reference design for the Army TSV provide the basis for HSVs in CLFSAT. Naval Sea Systems Command engineers have analyzed performance of HSV-X1 JOINT VENTURE and HSV-2 SWIFT to produce optimistic performance characteristics of payload versus speed versus range for this future HSV [Ref. 27]. Table 10 provides examples of these tradeoffs for two different ranges. It is clear from Table 10 that increasing speed or range, requires greater fuel loads with corresponding decreases in cargo capacity. The implemented Scenario 1 uses an HSV with fuel and cargo loads for the 1250 nautical mile range at 40 knots. Scenario 2 uses the 2500nm range numbers. Both scenarios subtract 100 stons of cargo capacity for magazine and embarked helicopter with pack-up kit weight.

	1250 nm Range		2500nm Range	
Speed (kts)	**Fuel Load (bbls)**	**Cargo (stons)**	**Fuel Load (bbls)**	**Cargo (stons)**
10	310	932	619	887
15	607	888	1214	800
20	881	848	1762	720
25	1250	794	2500	612
30	1548	751	3095	525
35	1770	733	3339	489
40	1821	711	3643	445

Table 10. Payload vs. Speed vs. Range Samples for notional HSV [After Ref. 27]

C. MEASURES OF EFFECTIVENESS AND CLFSAT OUTPUT

CLFSAT uses an internal statistical system to collect observations of various parameters of interest throughout the simulation execution. These observations are used to calculate statistics and generate graphs that depict Measures of Effectiveness (MOEs). There are several MOEs built into CLFSAT and detailed below.

1. Commodity Load Percentages

CLFSAT tracks the current percent of commodity capacity by time for each ship and each commodity. This allows easy visibility of the performance of the sustainment process. Violations of established commodity reserve levels can be examined and quantified by magnitude, duration, or frequency.

2. Inter-Replenishment and Inter-Consolidation Times

CLFSAT tracks time between replenishment events for each customer ship to reflect level of customer service provided to that particular ship during the scenario. Long delays between replenishments can indicate scenarios that are particularly difficult given the CLF force level and number of customer ships involved.

3. Theater Customer Wait Time (CWT)

This is the CWT for CASREP related parts from time of arrival in theater to time of delivery to the appropriate customer. Examination of these values between different scenarios can show differences in high-priority material distribution.

4. Theater Delays for PGM Delivery

This is the delay time (similar to CWT) for delivery of PGMs to aircraft carriers once the PGMs arrive in the theater. Examination of these values between different scenarios can show improvements in the rapid delivery of these critical munitions.

5. CLF Shuttle Ship Activity Levels & Cycle Times

CLFSAT also tracks the timing and quantities transferred for all UNREPs, CONSOLs, and INREPs for CLF shuttle ships. This provides visibility of how over or under tasked CLF shuttle ships are in a particular scenario. This information can be used for operations planning to increase or reduce the force levels and evaluate the effect on this MOE.

D. SCENARIOS

CLFSAT is capable of implementing any naval scenario. In order to best address COMLOGWESTPAC’s research questions, this thesis implements multiple scenarios involving a Major Combat Operation (MCO) in Korea. The scenario is hypothetical and not based on any actual Operations Plans. Force levels are derived from a 1992 New York Times article discussing Pentagon war plans [Ref. 28] and GlobalSecurity’s detailed discussion of Korea plans [Ref. 29], then modified by the current Fleet Response Plan, and forces available in May 2005. The scenarios are 60 days long, providing sufficient time to develop any apparent differences between naval logistics force structures. Each scenario is analyzed with multiple excursions. The following paragraphs, and Figure 13 and 14 describe the scenarios.

1. Korea MCO Scenario 1: FLS Sasebo Base Case

The scenario starts in May 2005 and begins with two days of indications and warnings of military activity along the DMZ in North Korea. This allows the Navy to sortie some of the Forward Deployed Naval Forces (FDNF) in Japan and to begin preparing other ships to deploy. Thus, on C-Day, the Kitty Hawk CSG has just put to sea in the Pacific, south of Yokosuka, and is able to begin transit immediately to an operating area in the northern Yellow Sea (aka the West Sea). The Kitty Hawk CSG arrives on station on C+2 and immediately begins conducting offensive and defensive air operations. The Nimitz CSG has recently deployed from San Diego and is already in transit across the Pacific. It will arrive on station in the Yellow Sea on C+10 and immediately begin offensive and defensive air operations. The Carl Vinson CSG deployed in February on an around-the-world cruise and on C-Day is preparing to depart the Arabian Gulf. A high-speed transit allows the Vinson CSG to arrive on station in the western Sea of Japan (aka the East Sea) by C+12, and also begin offensive air operations immediately. On C-day, the Ronald Reagan CSG is inport San Diego preparing to surge deploy. The CSG sails on C+4, arrives on station in the Sea of Japan on C+17, and immediately begins offensive air operations. The Abraham Lincoln CSG is inport Everett, WA on C-day also preparing to surge, and she sails for San Diego on C+3 to onload her air wing. The CSG deploys from San Diego on C+8, arrives on station in the Yellow Sea on C+21, and also immediately begins offensive air operations. The peculiarities of the Fleet Response Plan as it exists in May of 2005 mean that the first five of the CSGs available come from the Pacific Fleet. There are no more carriers to draw from in the Pacific Fleet, as the Stennis is in a 10 month Docking Planned Incremental Availability (DPIA) at Bremerton. The sixth and any additional CSGs must thus come from Atlantic Fleet carriers, all of which are inport, or in workups. The Truman CSG, having just returned from deployment is first on the list available to surge. Rather than sending the Truman CSG on a 23-day transit to Korea, the Navy decides to handle the Korean MCO with the five carriers already deployed, and deploys the Truman CSG to the Mediterranean and potentially the Arabian Gulf to dissuade any opportunistic action by other countries.

Normally, ESGs and SSGs deploy as well. If these forces operate within range of the carrier operating areas, they could operate as part of the "Sea Base" and fall under support of the CLF station ships. If they operate independently, they create additional requirements for CLF shuttle support. For the purpose of this analysis, this scenario does not implement ESGs and SSGs. The methodology of the Scenario Base Case implementation and comparison with the excursions means this omission will not change the results of the analysis. Specifics of this methodology are detailed below and in Chapter IV. This force deployment is presented in Figure 13.

To support this large selection of combatants, COMLOGWESTPAC begins the scenario with their normally assigned CLF shuttle ships as detailed in Table 3 on page 42. Additional CLF assets will augment as required to support the operations of the customer ships in the theater. San Jose (T-AFS 7) and Yukon (T-AO 202) are operating out of Singapore and will stay in place to support ships transiting through the Indian Ocean, Malacca Straits, and South China Sea. Concord (T-AFS 5), Guadalupe (T-AO 200), and Kiska (T-AE 35) are operating near Guam. These three ships will not be required in the Guam area, so depart for Sasebo on C+2 through C+4, arriving between C+6 and C+8. Kilauea (T-AE 26), not normally assigned to COMLOGWESTPAC, is just finishing a maintenance period in Guam when notified that she is needed to augment the normally assigned T-AEs. She departs for Sasebo on C+4, arriving in the area on C+8. Niagara Falls (T-AFS 3), John Ericsson (T-AO 194), and Shasta (T-AE 33) are operating around Japan, based out of Sasebo, and are prepared to support operations. Tippecanoe (T-AO 199) was transiting from Singapore to Sasebo to relieve John Ericsson, but will finish the transit and both ships will stay to provide additional oiler support. An additional oiler, Walter S. Diehl (T-AO 193), is operating out of San Diego in support of 3rd Fleet operations. She deploys on C+4 to arrive in the operations area on C+22.

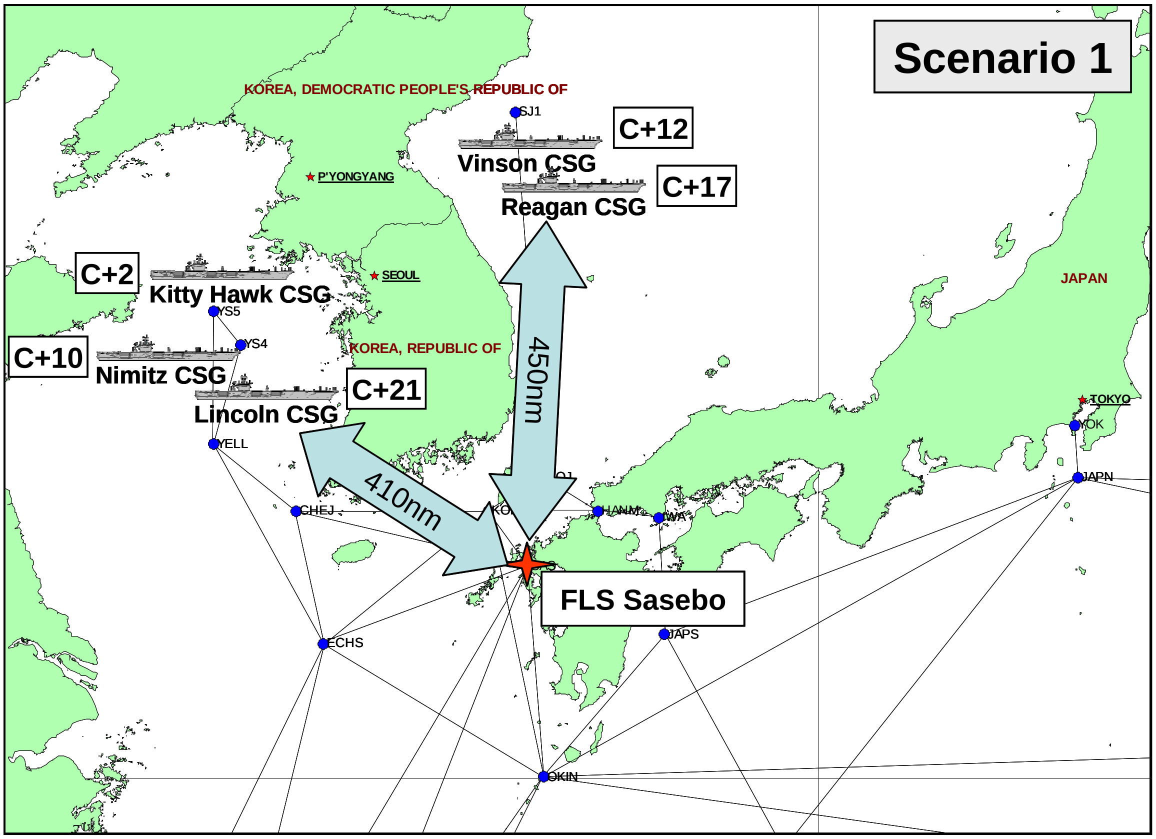

Figure 13. Korea MCO Scenario 1: FLS Sasebo

a. Excursion 1-1: Current CLF plus Two HSVs

The first excursion for Scenario 1 uses the same CLF force structure as the Base Case, but adds HSVs operating out of Sasebo. This excursion adds two HSVs, one for each carrier operating area, as it assumes that would be the minimum effective addition, but any number could be added. These HSVs will continuously shuttle from Sasebo to customer ships in the operating areas of the Yellow Sea and the Sea of Japan. The HSVs will primarily carry PGMs, with general ordnance and stores filling any remaining cargo capacity. PGMs, general ordnance and stores are transferred to the primary assigned customer for each cycle, then the remainder of the assigned customers are visited until no cargo remains. While the HSVs are also tasked to carry CASREP related high priority material, they are not required to for this scenario as the small size of the Korea MCO Theater place all operating areas within COD range. This small theater also allows use of the HSV specifications for 1250 nm range at 40 knots.

b. Excursion 1-2: Reduced Current CLF plus Two HSVs

This excursion seeks to take advantage of any efficiencies created in Excursion 1 by inclusion of the two HSVs. The non-HSV CLF force structure from Excursion 1 will be reduced to the minimum sufficient to allow a feasible run, and then compared to the base case.

2. Korea MCO Scenario 2: FLS Guam Base Case

This a modification of Scenario 1 that attempts to stress any results from that scenario by hypothesizing a North Korean nuclear blackmail of Japan, forcing the withdrawal of access to Japanese logistics ports. All customer ship operations remain the same as Scenario 1, but the loss of Sasebo, Iwakuni, Yokosuka, and Okinawa forces the U.S. to fall back on the closest assured Forward Logistics Site (FLS), Guam. This greatly changes the dynamic of supportability, as one-way transits from the FLS port to the customers roughly quadruple, increasing from 420 nautical miles to 1840 nautical miles. This large increase in required shuttle cycle time drives a requirement for additional CLF shuttle ships, which are drawn from other theaters. Additionally, the CLF shuttle ships will be the sole means of distributing CASREP related high priority material, as all operating areas are outside COD range from Guam. Developing the specific CLF force structure is part of the Base Case, detailed in Chapter IV. Figure 14 illustrates this scenario.

a. Excursion 2-1: Current CLF plus Two HSVs

This excursion for Scenario 2 uses the same CLF force structure as the Scenario 2 Base Case, as specified in Chapter IV, but adds two HSVs operating out of Sasebo. These HSVs will continuously shuttle from Guam to customer ships in the operating areas of the Yellow Sea and the Sea of Japan. In addition to PGMs, the HSVs will have priority over the CLF shuttle ships on CASREP related high priority material. General ordnance and stores will fill any remaining cargo capacity. The larger transit distances in this scenario forces use of the HSV specifications for 2500 nm range at 40 knots, and an assumption that HSVs refuel from the station ships in conjunction with

CONSOLs, before returning to port. HSV specifications are available for 4000nm range, allowing round trips, but cargo capacity is negligible, making this option not desirable.

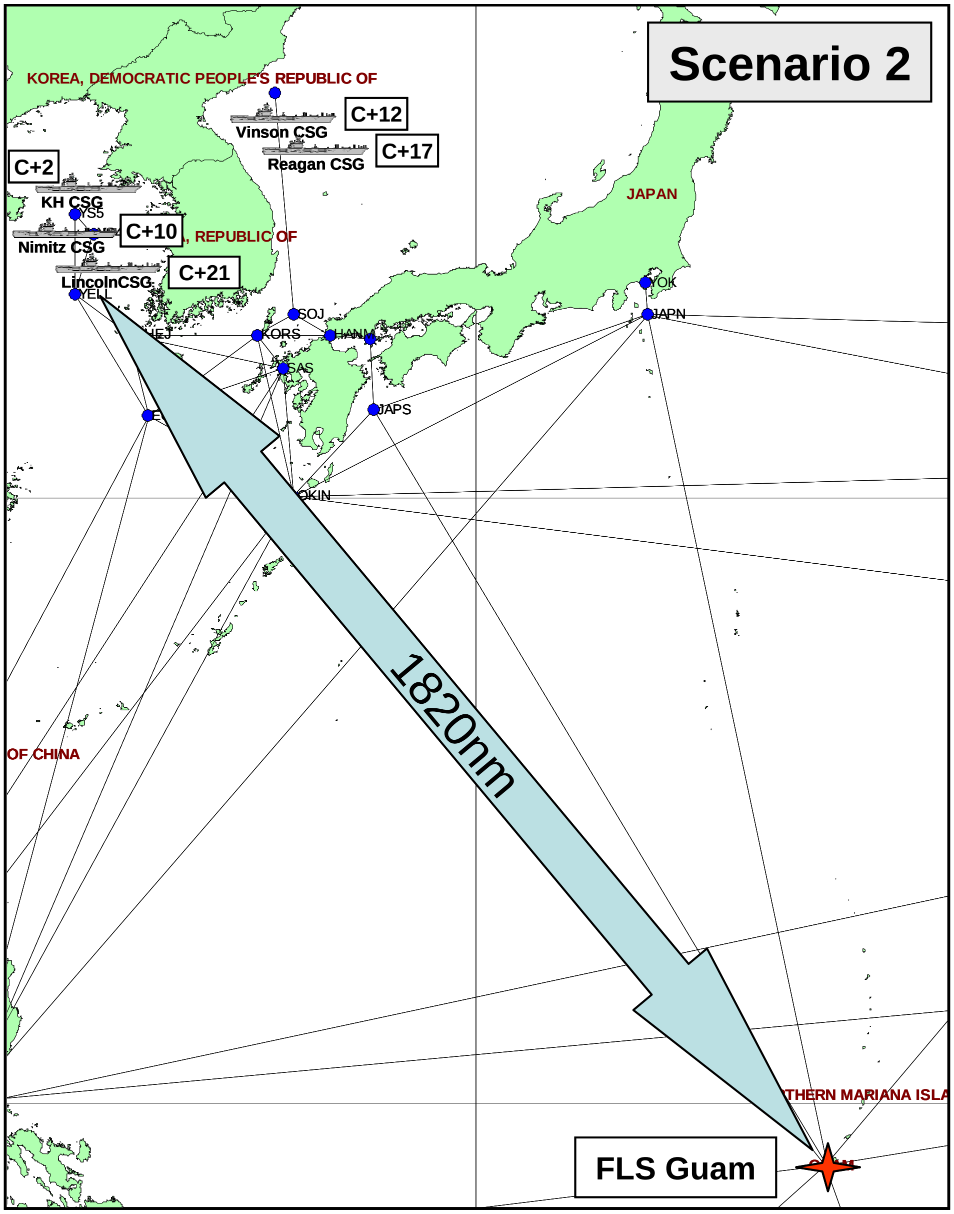

Figure 14. Korea MCO Scenario 2: FLS Guam

IV. RESULTS AND ANALYSIS

A. KOREA MCO SCENARIO 1: FLS SASEBO

1. Base Case: Current CLF Only

Development of the Scenario 1 Base Case required several successive CLFSAT runs. The scenario initially consists of the naval operations of the customer ships and all the normally assigned COMLOGWESTPAC CLF shuttle ships (see Table 3, p. 42), placed in their traditional operating areas (Singapore, Guam, and Sasebo). A CLFSAT run produces the MOEs, which are evaluated to determine if all customer ships are sufficiently supported. The customer ships in this initial run displayed severe violations of reserve commodity levels, with some ships unable to perform the scripted scenario operations. To perform analysis of this scenario, a feasible and valid Base Case is required. Therefore, these sustainment deficiencies must be corrected, which involves iterative alteration of the CLF force structure, rerun of CLFSAT, and reevaluation of the MOEs. Actual alterations to the CLF force structure involved shifting the assigned CLF shuttles within the theater and augmenting with additional CLF from outside the theater until the customer ships can be sustained and are able to conduct all scripted scenario operations. An additional oiler, USNS Walter S. Diehl (T-AO 193), is required to augment from outside the theater to rectify some JP5 shortages in the CSGs late in the scenario. Additionally, the original COMLOGWESTPAC force of two assigned T-AEs, which in terms of capacity should be sufficient to sustain the combat forces, proved insufficient in the later periods of the scenario when all five CSGs are conducting operations. This was not an insufficient capacity issue, but a timing issue, specifically an inability to get the two T-AEs to two separate sides of the Korean peninsula as often as necessary. These problems are rectified by adding an additional ammunition ship, USNS Kilauea (T-AE 26), to the scenario. The final Base Case shuttle CLF force structure is five T-AOs (+ 1), three T-AEs (+ 1), and three T-AFSs (+ 0).

Thus, the Scenario 1 Base Case assumes supportability of the scripted naval operations for the Korea MCO and verifies such with a CLFSAT run after augmenting normal COMLOGWESTPAC CLF assets. Since the Base Case is feasible by design, analysis within that one case is neither interesting nor relevant. The analysis is only valid when comparing MOEs across excursions, which vary CLF force structure within the same scenario. To this end, the results for the Base Case are only presented where relevant in comparison with the following excursions.

2. Excursion 1-1: Current CLF plus Two HSVs

This excursion is composed of the Base Case's proven feasible CLF allocation augmented by two HSVs. The HSVs should allow improvements in distribution of PGMs, ordnance, and stores. Due to the small size of the Korea MCO Theater, they should not show significant improvement in distribution of CASREP related priority material, as the majority of the theater is within COD range. The following sub-sections present the results of Excursion 1-1 compared to the Base Case. These two cases are compared and evaluated using the MOEs of Commodity Load Percentages, Inter-Replenishment Times, CASREP Theater Customer Wait Time, Theater Delay for PGM Delivery, and an analysis of Ordnance CONSOLs.

a. Commodity Load Percentages

Examining the commodity load percentages of customer ships over time also illustrates differences in the performance of the two compared CLF force structures. In this scenario, all customer ships operate in CSGs with CLF station ships. Since the Base Case adds CLF shuttles until the station ships are capable of replenishing their assigned combatants as required, the commodity percentages of the combatants are mostly uninteresting as they get what they need from the station ship when they need it. On the other hand, the CLF station ship is dependent on the dynamic shuttle cycles, so will exhibit the most variation in its commodity loads based on the excursions that vary shuttle CLF force structure and employment. The ability to look at the commodity levels of only the station ships simplifies the analysis and makes differences between excursions much more visible. This analysis will also only examine station ship ordnance and stores percentages, as wet products are not effectively carried by HSVs, thus are not part of the comparison.

Figure 15 presents the ordnance percentage for one of the station ships as tracked throughout the scenario; the others follow similar patterns, so are not presented. For the first 12 days, the stations ship's CSG is transiting from the Arabian Gulf to the operating area in the Sea of Japan. Once on station, the carrier commences offensive air operations, and requires ordnance transfers from this station ship. The Base Case ordnance percentage shows three reserve violations (levels below 30%), has a lower mean ($\mu = 0.70$), and appears to vary more ($\sigma = 0.29$) than Excursion 1-1. In Excursion 1-1, the HSV's continuous small ordnance shipments (filling space not taken by PGMs) is sufficient to maintain the station ship in a better supply state with less variation ($\mu = 0.77$, $\sigma = 0.21$). Additionally, despite the same heavy ordnance use in each case, the station ship violates reserve levels only once when supported by the HSVs in Excursion 1-1.

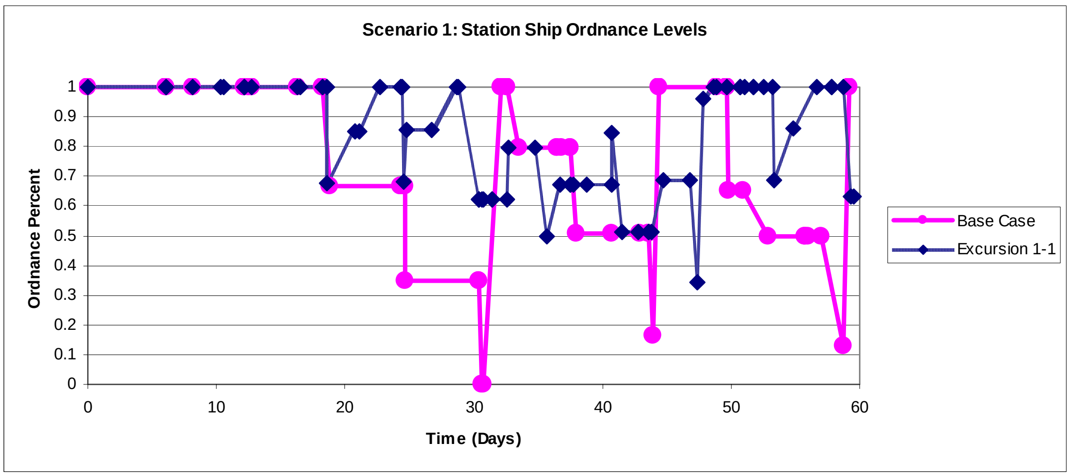

Figure 15. Scenario 1: Station Ship Ordnance Percentage between Base Case and Excursion 1-1

Figure 16 presents the stores percentages for the same station ship. Both graphs are on the same scale, so it is obvious that levels of stores are never a sustainment issue. It is interesting to note that in both the Base Case and Excursion 1-1, the T-AFS Combat Stores ships never leave port, as there is never a demand great enough to require their services. All of the stores increases in the Base Case come from the small stores capacity of the T-AOs, which is sufficient to sustain the customer ships well above reserve levels of stores. As before, the Base Case stores level percentage does stay lower with more variability ($\mu = 0.89$, $\sigma = 0.08$), while Excursion 1-1 exhibits a higher mean and less variability ($\mu = 0.96$, $\sigma = 0.06$).

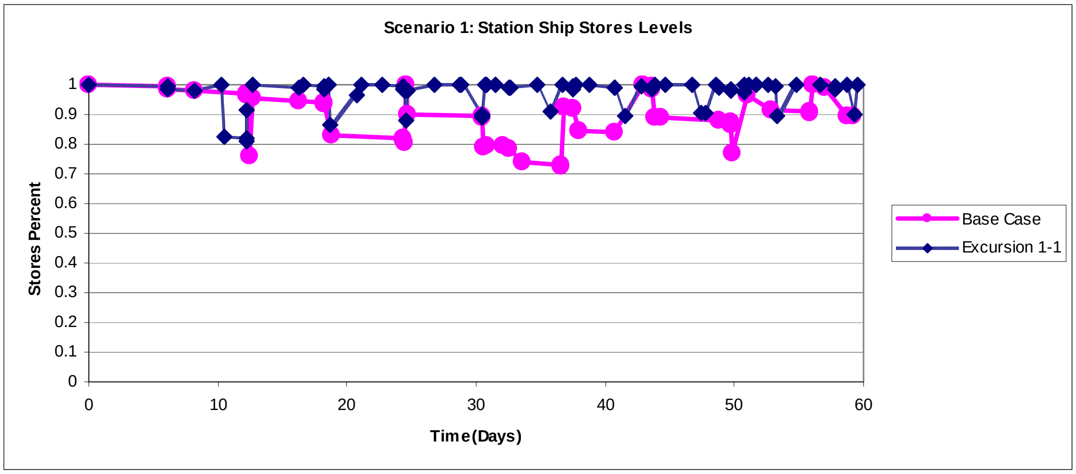

Figure 16. Scenario 1: Station Ship Stores Percentage between Base Case and Excursion 1-1

b. Station Ship Inter-CONSOL Times

Inter-CONSOL times for an individual station ship directly reflect the customer service level for that ship. While each CONSOL may not be critical, each is an opportunity to provide a needed service, whether it is transfer of high-priority material, ordnance, mail, or simply fresh fruits and vegetables. In the Base Case, these CONSOLs are the traditional high quantity transfers from large single commodity CLF shuttle ships. Excursion 1-1 mixes these traditional CONSOLs with smaller HSV hits for PGMs, ordnance, and stores. Despite their scale difference, these HSV hits are considered CONSOLs for this analysis.

Figure 17 presents one station ship's inter-CONSOL times throughout the duration of the scenario. For the first 12 days, the stations ship's CSG is transiting from the Arabian Gulf to the operating area in the Sea of Japan. In the Base Case, the inter-CONSOL time remains high early in the simulation while the ships of the CSG deplete initially full stocks. After the first 30 days, it appears to stabilize around four to six days between CONSOLs. The curve for Excursion 1-1 is dramatically different. It is clear that once the HSVs begin running, they hit the station ship every 48 hours. A combination of an HSV CONSOL with a CLF shuttle ship CONSOL in a short period causes the dips below 48 hours. Scheduled arrivals of airlifted PGMs at the FLS drive this 48-hour timing for the HSVs. The relatively short transit distances in this Korea MCO scenario allow the HSVs to cycle from port to customer and back to port in roughly 24 hours, so even shorter inter-CONSOL times are possible if more rapid arrival of priority loads forces them. Overall, this MOE shows that, in a small theater of operations, like Korea or the Arabian Gulf, HSVs can hit the station ships quite frequently.

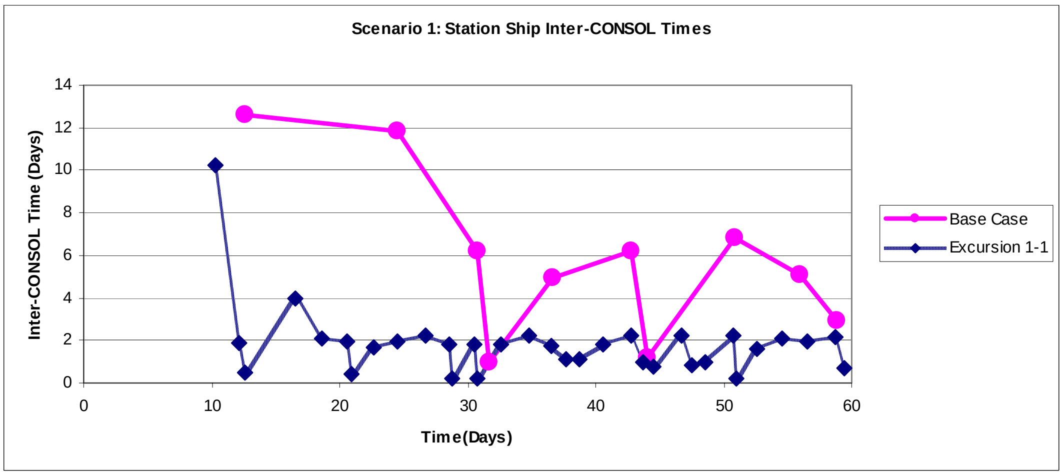

Figure 17. Scenario 1: Station Ship Inter-CONSOL Times between Base Case and Excursion 1-1

c. Theater Customer Wait Time (CWT)

In these two cases, the in-theater portion of CWT for distribution of CASREP parts requisitions is identical as presented in Table 11. While HSVs are tasked with delivery of CASREP high-priority material, the Korea MCO operations areas are all within range of COD aircraft, which have priority on deliveries of this material. The Korea MCO scenario also has all customer ships operating within range of an aircraft carrier, thus allowing COD distribution to the CSG, followed by VOD distribution within the CSG. These delay times are also very short due to the COD/VOD delivery method. Reliance on CLF Shuttle or HSV delivery should greatly increase these delay times. In any scenario with CSGs operating outside COD range, or with independent ESGs, SSGs, or customer ships, these numbers will differ between the cases. This presents an opportunity for an excursion to investigate this area.

	CASREP Requisition Theater Delay (Hours)	
	Base Case	**Excursion 1-1**
95% CI High	33.47	33.47
Mean	30.82	30.82
95% CI Low	28.18	28.18

Table 11. Scenario 1: CASREP Requisition in Theater Distribution Delay between Base Case and Excursion 1-1

d. Theater Delays for PGM Delivery

The in-theater portion of delay time in the distribution of critical PGMs is the single largest difference between the two cases. This delay is specifically defined as the time in hours between PGM arrival via airlift at the Forward Logistics Site (Sasebo) and their delivery to the aircraft carriers. In the Base Case, T-AEs distribute PGMs from the FLS to the CSGs. Unfortunately, the T-AEs only do this as part of their normal demand-based shuttle cycling. This, combined with their slow speed, leads to a huge delay in delivery of PGMs, typically in excess of 12 days. Additionally, the T-AEs are only able to deliver 144 of the 180 specific PGM shipments airlifted during the 60-day run of the scenario. The rest remained at the FLS awaiting pickup.

In comparison, the Excursion 1-1 HSVs, assigned the explicit purpose of PGM delivery, generate a delay of roughly 13 hours, just long enough to load the munitions then transit directly at high speed to the customer. Due to this rapid turn-around, the HSVs delivered significantly more of the PGM shipments, 174 of the 180 airlifted. To best distribute PGMs among the carriers, HSVs alternate PGM deliveries among their assigned customers.

It may be more constructive to examine these same statistics for the Excursion 1-2 and Scenario 2, explored later, which, as they stress the model, should cause the T-AEs to cycle more often, reducing the delay numbers. Regardless, the HSVs will still perform this niche mission significantly faster than current-day CLF, only the scale of the difference may vary. Table 12 summarizes the results for this scenario.

	PGM Theater Delay (Hours)	
	Base Case (144 of 180 delivered)	**Excursion 1-1 (174 of 180 delivered)**
95% CI High	343.00	13.27
Mean	313.28	12.97
95% CI Low	283.56	12.67

Table 12. Scenario 1: Precision Guided Munitions (PGMs) in Theater Distribution Delay between Base Case and Excursion 1-1

e. Ordnance CONSOLs

The only remaining interesting point of comparison is the ordnance CONSOLs themselves. Table 13 presents numbers of ordnance CONSOLs and quantity of ordnance transferred by each T-AE and HSV for both cases. In Excursion 1-1, when HSVs were also operating, the T-AEs as a group performed nearly 40% fewer CONSOLs. This reduction in T-AE demand resulted from the two HSVs delivering more than half of the total ordnance tonnage. While, individually, the HSV carrying capacity is a small fraction of the T-AEs, their high speed in this Korea MCO scenario created “virtual capacity”. It is important to point out that HSVs only load general ordnance to fill remaining cargo capacity after loading any required PGM shipments. If PGM shipments are bigger, or arrive more often, this could reduce the general ordnance carrying capacity of the HSVs, producing performance different from this case.

Also in Excursion 1-1, Kilauea (T-AE 26), originally added to make the base case feasible, performed zero CONSOLs. Apparently, the availability of two HSVs also rectified the scheduling issues that prevented the original two T-AEs from attaining a feasible schedule. Additionally the total number of T-AE CONSOLs appears within the capability of a single T-AE. This is motivation for performing Excursion 1-2, which will include the two HSVs with a reduced CLF force structure, presented shortly.

	Ordnance CONSOLs			
	Base Case		Excursion 1-1	
T-AEs	**Events**	**Tonnage(stons)**	**Events**	**Tonnage (stons)**
Kilauea (T-AE 26)	2	4,581	0	0
Shasta (T-AE 33)	8	18,149	5	8,750
Kiska (T-AE 35)	3	7,027	3	4,641
TOTAL	*13*	*29,757*	*8*	*13,391*
HSVs				
HSV 1	-	-	15	6,737
HSV 2	-	-	22	8,565
TOTAL	-	-	*37*	*15,302*

Table 13. Scenario 1: Ordnance CONSOLs between Base Case and Excursion 1-1

3. Excursion 1-2: Reduced Current CLF plus Two HSVs

This excursion tests the limits of the benefits gained from the two HSVs. Excursion 1-2 starts with the force structure from Excursion 1-1 and reduces the CLF shuttles ships to the minimum level below which serious sustainment issues appear. Based on the results from the Excursion 1, the force levels can be reduced to zero T-AFSs, and one T-AE, with T-AOs unchanged. The following sub-sections present the results of Excursion 1-2 as compared to the Base Case. Theater Customer Wait Time remains uninteresting due to the Korea MCO scenario and is excluded. PGM Theater Delay and Inter-CONSOL times, heavily dependent on the unchanged HSVs, end up identical to Excursion 1-1, so are also excluded.

a. Commodity Load Percentages

The analysis of this excursion presents only Ordnance Load Percentages, as Stores Load Percentages are identical to Excursion 1-1 where T-AFSs are not required. Figures 18-22 present the ordnance percentage for each of the station ships as tracked throughout the scenario. For the first two station ships, Figures 18 & 19, the ordnance percentage for the Base Case averages much lower than the Excursion case and with much larger variation. For the last three station ships, Figures 20-22, the difference between the cases is much less pronounced. The Base Case shows 13 total reserve violations, distributed evenly among the station ships. Excursion 1-2 shows six violations, all from the last three station ships.

What is the obvious operational difference between the first two station ships and the last three? The first two station ships are operating with CSGs in the Sea of Japan (East Sea) and HSV2 is dedicated to service them. The last three station ships operate with CSGs in the Yellow Sea (West Sea) and HSV1 is dedicated to service them. HSV1 is therefore servicing more customers, so each will receive fewer hits. Aggravating this situation, 40nm separates the operating areas of HSV1's three station ships, causing additional transit time for multiple CSG hits in a single run. These different examples show the effect of many HSV hits (the first two) compared to few HSV hits (the last three). Station ships that receive many HSV hits have a completely altered supply profile, with significantly higher mean commodity levels and significantly reduced variation. Those that receive few HSV hits, only benefit from a reduction in the downward slope of their ordnance consumption, increasing the period of their potential reserve violations. Station Ship 4, in Figure 21, is the most extreme example of limited HSV hits, with no reduced slope, only a single positive shift in the curve.

In general, all of the Excursion 1-2 ordnance levels are operationally acceptable. This indicates that in the small Korea Theater with a nearby FLS only, two HSVs can act in place of two AEs.

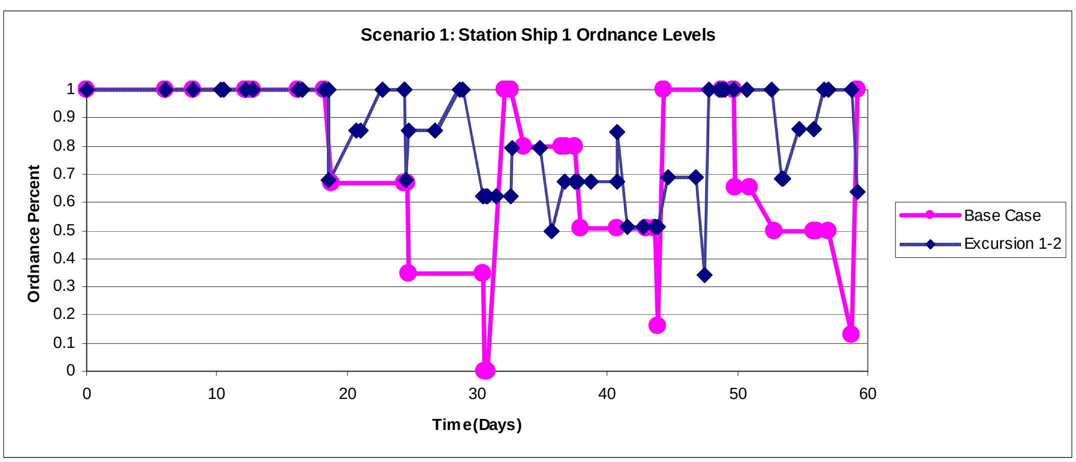

Figure 18. Scenario 1: Station Ship 1 Ordnance Percentage between Base Case and Excursion 1-2

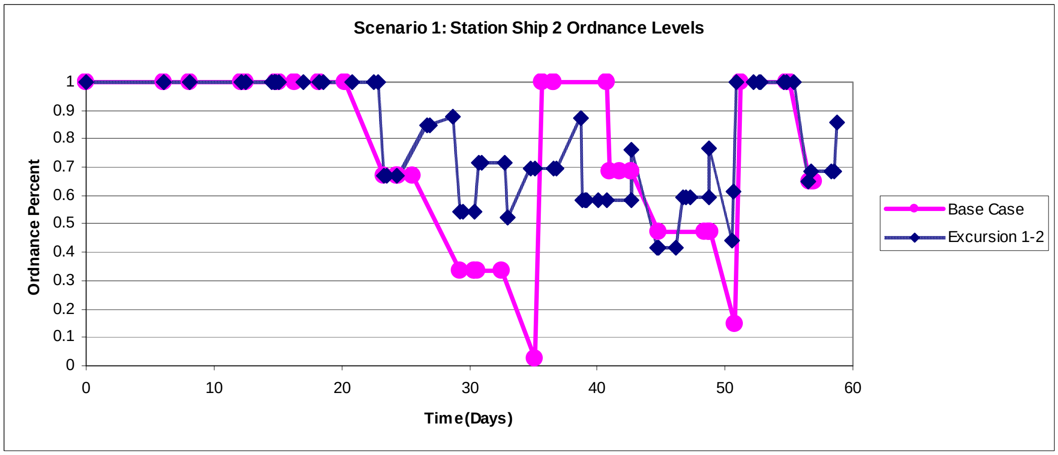

Figure 19. Scenario 1: Station Ship 2 Ordnance Percentage between Base Case and Excursion 1-2

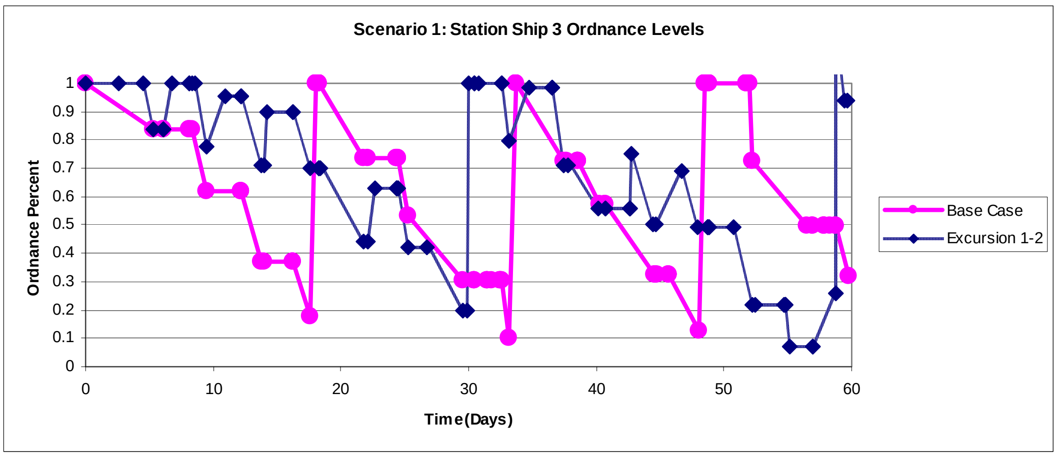

Figure 20. Scenario 1: Station Ship 3 Ordnance Percentage between Base Case and Excursion 1-2

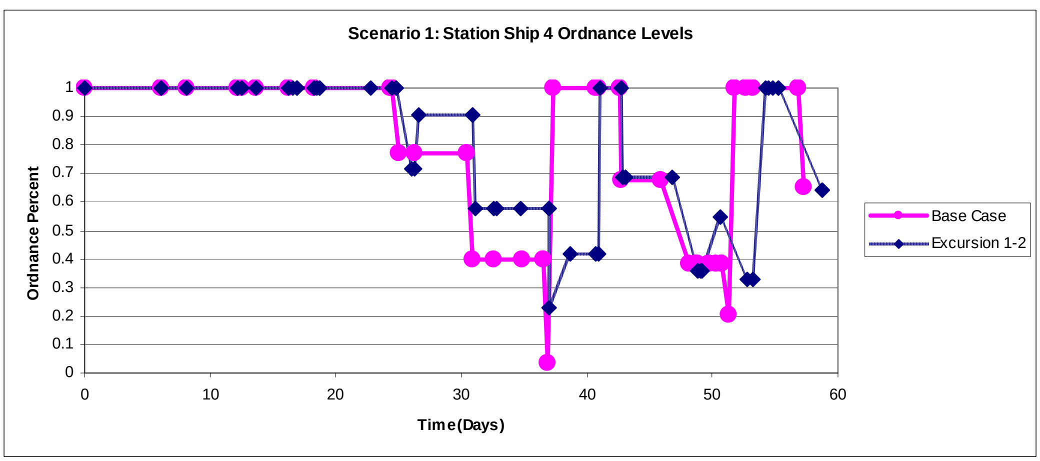

Figure 21. Scenario 1: Station Ship 4 Ordnance Percentage between Base Case and Excursion 1-2

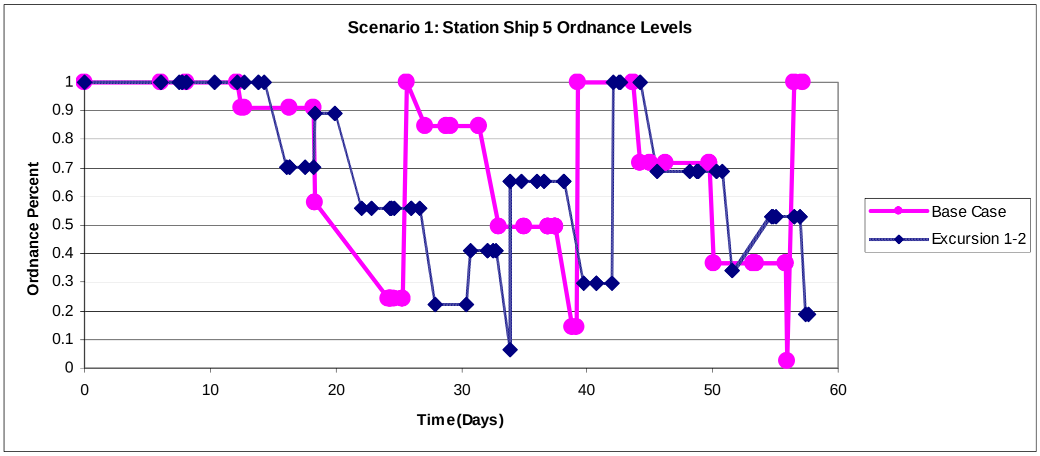

Figure 22. Scenario 1: Station Ship 5 Ordnance Percentage between Base Case and Excursion 1-2

b. Ordnance CONSOLs

Table 13 presents numbers of ordnance CONSOLs by each T-AE or HSV and total ordnance transferred for the base case and this reduced CLF excursion. This data combined with the ordnance commodity percentages for the station ships shows clearly that in this Korea MCO scenario only, two HSVs are able to fully substitute for two T-AEs. In fact, the ordnance tonnage moved by the two lost T-AEs in the base case is almost completely picked up by the two HSVs. It is very important to emphasize that the “two HSVs equals two T-AEs” result is only known to be applicable in the small Korea MCO Theater for this specific scenario. Any increase in customer ships or distances (with the coinciding reduction in HSV cargo capacity), could modify this finding. Scenario 2, with the FLS in Guam, presented next, will provide further illumination of this finding.

T-AEs	Ordnance CONSOLs Base Case Events	 Tonnage(stons)	 Excursion 1-2 Events	 Tonnage (stons)
Kilauea (T-AE 26)	2	4,581	-	-
Shasta (T-AE 33)	8	18,149	8	13,777
Kiska (T-AE 35)	3	7,027	-	-
TOTAL	*13*	*29,757*	*8*	*13,777*
HSVs				
HSV 1	-	-	15	6,737
HSV 2	-	-	22	8,565
TOTAL	-	-	*37*	*15,302*

Table 14. Scenario 1: Ordnance CONSOLs between Base Case and Excursion 1-2

B. KOREA MCO SCENARIO 2: FLS GUAM

1. Base Case: Current CLF Only

Development of the Scenario 2 Base Case also required several successive CLFSAT runs to determine the numbers and types of CLF required for feasibility. The scenario builds on the Scenario 1 Base Case, with no changes to the naval operations of the customer ships and starts with the same CLF shuttle ships that were determined sufficient in the Scenario 1. Loss of support from Japan is simulated by removing the ports at Sasebo, Yokosuka, Iwakuni, and Okinawa from CLFSAT and changing the FLS from Sasebo to Guam. The iterative process of CLFSAT run, evaluation of MOEs, and augmentation of the CLF force structure continues until all customer ships can be sustained and are able to conduct all scripted scenario operations. Actual alterations to the CLF force structure involved shifting the assigned CLF shuttles within the theater and augmenting additional T-AOs from outside the theater. The final Base Case shuttle CLF force structure is twelve T-AOs, three T-AEs, and three T-AFSs.

Twelve T-AOs intuitively seems too many, given MSC only operates 13 with another in reserve. This is easily explained when the scenario is examined in detail. The mutually exclusive operating areas (Yellow Sea and Sea of Japan), each at 1800+nm distance from the FLS and with 750nm between them, make it impossible for one CLF shuttle ship to service both areas in a short period. The distance also causes a significantly longer cycle time than Scenario 1, so that when a CLF shuttle ship reaches the operating area, it is likely to transfer its entire commodity load to one CLF station ship. This also makes it unable to service another customer within the same operating area before returning to port for replenishment. The combination of these factors effectively doubles replenishment requirements. A fully optimized schedule with no slack could potentially reduce this requirement to roughly ten T-AOs, and combining all five CSGs into one operating area could reduce it further. The requirement for three T-AEs supports a rough doubling of the ordnance replenishment requirement, over 1-2 T-AEs actually required in the Scenario 1 Base Case. As in Scenario 1, the 3 T-AFSs are technically not required, but are included for tradition.

Given this process, the resulting Scenario 2 Base Case assumes supportability of the scripted naval operations, so analysis within that one case is not relevant. The analysis is only valid when comparing MOEs across cases, which vary CLF force structure within the same scenario. To this end, the results for the Scenario 2 Base Case are presented where relevant in comparison with the following excursions.

2. Excursion 2-1: Current CLF plus Two HSVs

This excursion tests whether the benefits gained by adding HSVs in Scenario 1 also apply at greater distances. These greater distances thus reduce HSV cargo capacity due to having to devote more deadweight to fuel. The following sub-sections present the Scenario 2 Base Case as compared with Excursion 2-1 and in some cases, data from Scenario 1. This analysis uses all MOEs as the increase in transit distances changes the scenario significantly.

a. Commodity Load Percentages

Examining the commodity load percentages over time should show the effects of long CLF shuttle cycle times and indicate whether HSVs play any role in reducing those effects. Figures 23-27 present the ordnance percentage for each of the station ships as tracked throughout Scenario 2. As expected, these look much worse overall than Scenario 1. The ordnance percentage for the Base Case averaged only slightly lower overall than Excursion 2-1 and variation was very similar. For the most part, HSV hits only reduced the downward slope of ordnance consumption slightly or shifted reserve violations to the right. Station ship 1 received the most HSV hits and consequently performed the best. The Base Case shows eleven total reserve violations, distributed evenly among the station ships and of much longer duration than in Scenario 1. Excursion 2-1 shows ten total violations, the majority from the last three ships (those on station in the Yellow Sea). It is important to note that these reserve violations and outages were experienced only on the station ships; their assigned carriers maintained sufficient ordnance to conduct all required operations.

Overall, the effect of the HSVs on ordnance levels in Scenario 2 was significantly less than in Scenario 1. This is a combined factor of halved cargo capacity and quadrupled transit time. Doubling the number of HSVs available, as was required for the other CLF shuttles would seem reasonable and may improve performance.

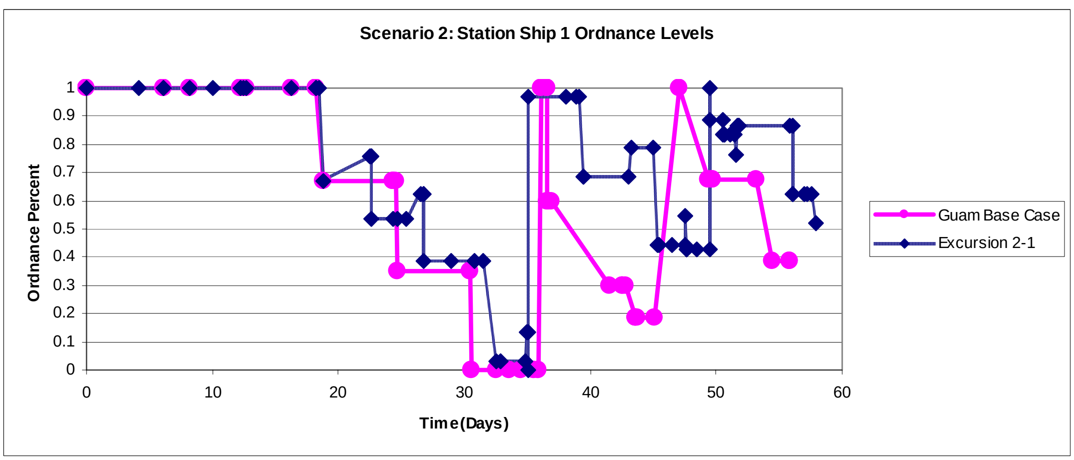

Figure 23. Scenario 2: Station Ship 1 Ordnance Percentage between Base Case and Excursion 2-1

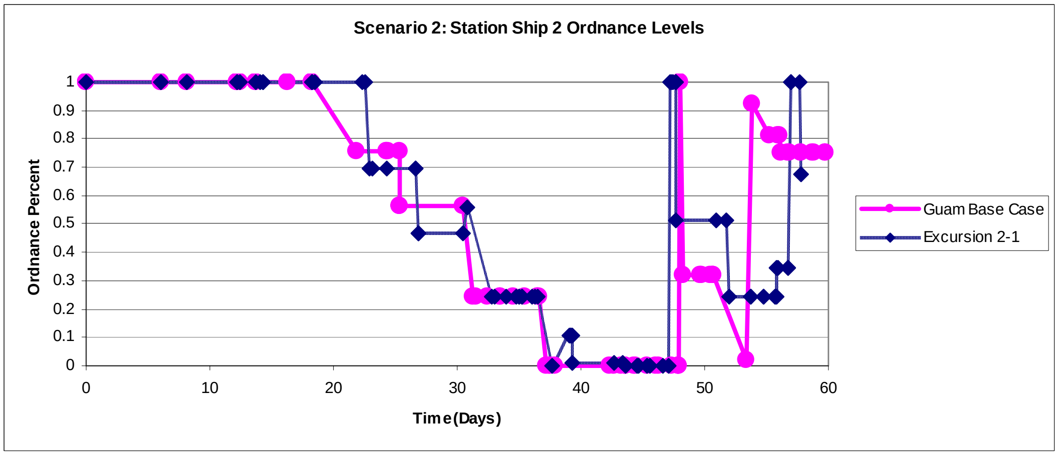

Figure 24. Scenario 2: Station Ship 2 Ordnance Percentage between Base Case and Excursion 2-1

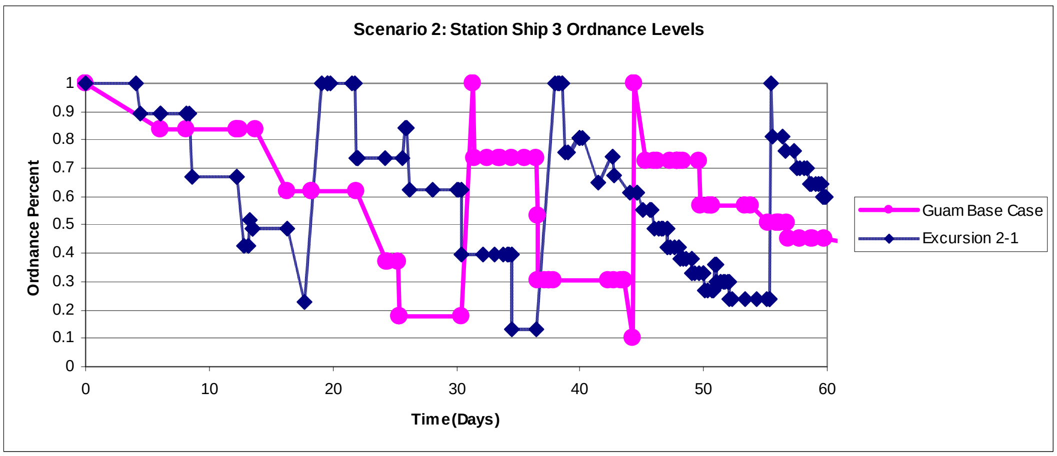

Figure 25. Scenario 2: Station Ship 3 Ordnance Percentage between Base Case and Excursion 2-1

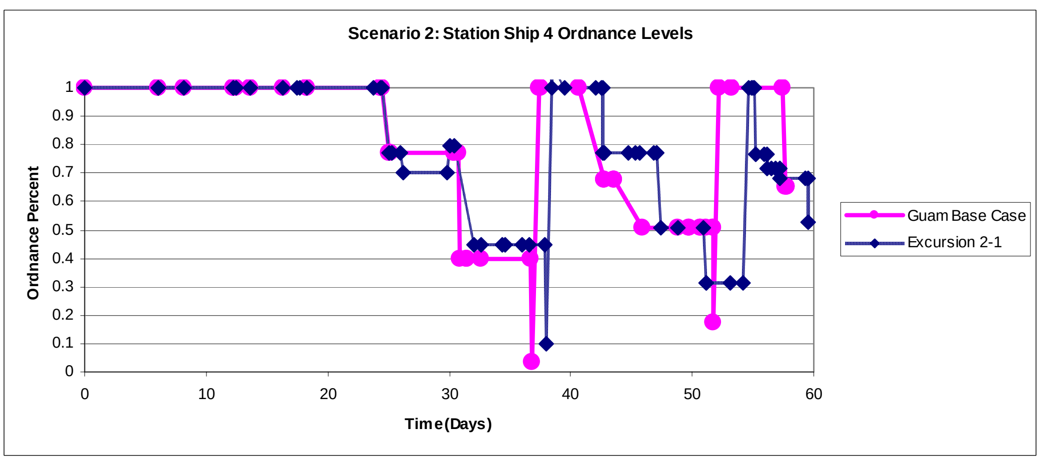

Figure 26. Scenario 2: Station Ship 4 Ordnance Percentage between Base Case and Excursion 2-1

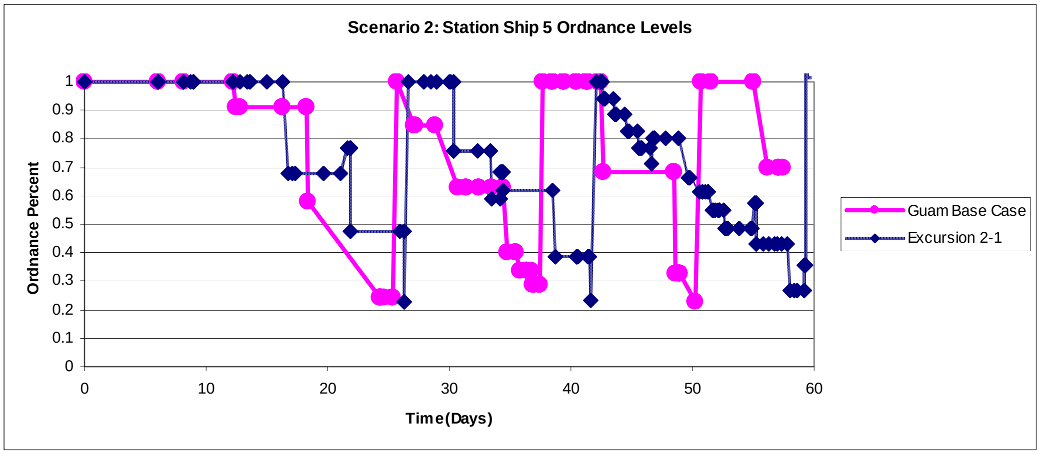

Figure 27. **Scenario 2: Station Ship 5 Ordnance Percentage between Base Case and Excursion 2-1**

Figure 28 presents the stores percentages for the Station Ship 1. This graph is again on the same scale, so it is obvious that even in Scenario 2, levels of stores are never a sustainment issue. As in Scenario 1, the T-AFS Combat Stores ships never leave port, as there is never a danger of customer ships depleting the stores stocks maintained on the station ships sufficiently to cause a pure stores CONSOL. Again, the periodic small stores increases seen in Figure 28 are all attributable to the AO deck load items in the Base Case, and a combination of the AO deckload with small HSV hits in the excursion. The unfortunate aspect of this lack of T-AFS cycling is that it removes an additional method for high priority CASREP parts distribution to customers. As before, the Base Case stores level percentage does stay lower with more variability ($\mu = 0.89$, $\sigma = 0.08$), while Excursion 2-1 exhibits a higher mean and slightly less variability ($\mu = 0.93$, $\sigma = 0.07$). Given the range of the data, the differences are insignificant from a sustainment standpoint.

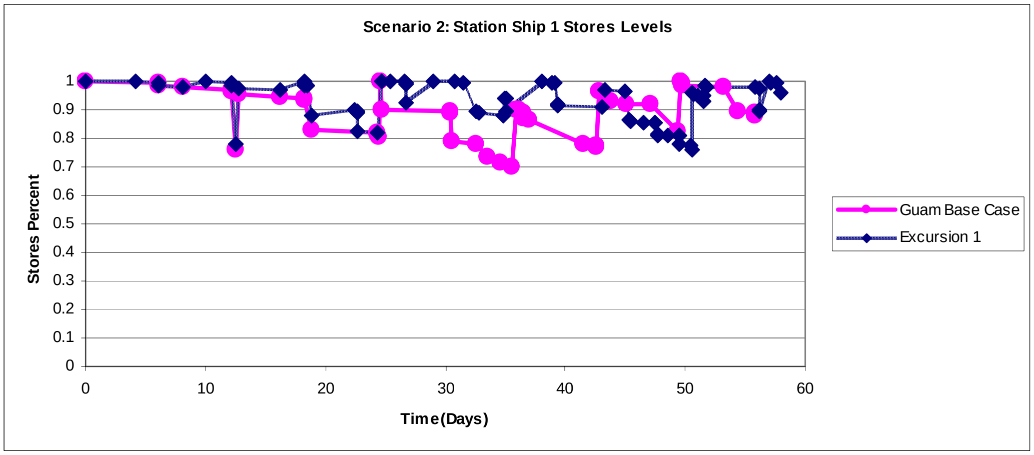

Figure 28. Scenario 2: Station Ship 1 Stores Percentage between Base Case and Excursion 2-1

b. *Station Ship Inter-CONSOL Times*

Figure 29 presents Station Ship 1's inter-CONSOL times throughout the duration of Scenario 2. As in Scenario 1, the Base Case inter-CONSOL time remains high early in the simulation while the ships of the CSG deplete initially full stocks. After the first 35 days, it appears to stabilize around three days between CONSOLs. The curve for Excursion 2-1 is dramatically different initially, with hits every 4-6 days, but stabilizes between two to four days after the first month, much like the Base Case. Unlike Scenario 1, a faster turn-around does not seem possible in this more strenuous scenario. Overall, this MOE shows that HSVs still allow more frequent hits for the station ships, but the effectiveness of these hits is indicated by other MOEs.

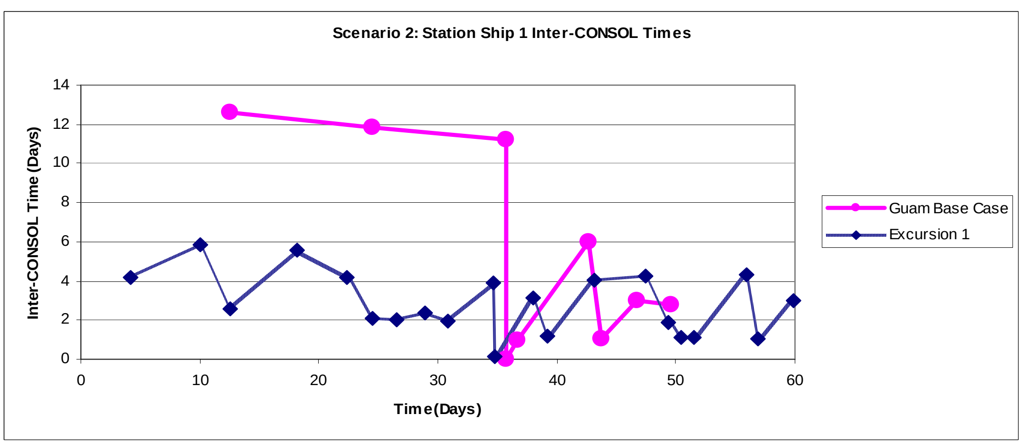

Figure 29. Scenario 2: Station Ship 1 Inter-CONSOL Times between Base Case and Excursion 2-1

c. *Theater Customer Wait Time (CWT)*

Scenario 2, with the FLS outside COD range, allows Theater CWT for CASREP high-priority material to differ between the Base Case and Excursion 2-1. The comparison is presented in Table 15. The results clearly indicate the HSVs in the excursion produce a significant reduction in the delay time; in fact, the HSVs deliver the material four times faster than the standard CLF shuttle ships. This positive result partially counteracts the lack of benefit gained for ordnance levels due to the less frequent and smaller cargo capacity HSV hits imposed by the long transit distances in this scenario.

	CASREP Requisition Theater Delay (Hours)	
	Guam Base Case	**Excursion 2-1**
95% CI High	573.97	137.16
Mean	469.60	129.17
95% CI Low	365.23	121.19

Table 15. Scenario 2: CASREP Requisition in Theater Distribution Delay between Base Case and Excursion 2-1

d. *Theater Delays for PGM Delivery*

The in-theater portion of delay time in the distribution of critical PGMs also differs significantly between the Base Case and this excursion. For Scenario 2, this delay is the time between PGM arrival via airlift at the FLS in Guam and their delivery to the aircraft carriers. The results are summarized in Table 16. In the Base Case, the three T-AEs distribute PGMs as part of their normal demand-based shuttle cycling, with a delay typically greater than 17 days. Additionally, the T-AEs are only able to deliver 126 of the 180 specific PGM shipments airlifted during the 60-day run of the scenario, with remainder still at the FLS awaiting pickup.

The Excursion 2-1 HSVs perform significantly faster, generating a delay of roughly 4 days. Again, as in Scenario 1, due to this rapid turn-around, the HSVs delivered significantly more of the PGM shipments, 162 of the 180 airlifted. These deliveries were distributed evenly among the CSGs. This finding directly reinforces a similar finding for Scenario 1. Even in this much more stressed scenario, HSVs are able to provide a four-fold improvement in speed of PGM distribution.

	PGM Theater Delay (Hours)	
	Guam Base Case (126 of 180 delivered)	**Excursion 2-1 (162 of 180 delivered)**
95% CI High	466.00	106.60
Mean	428.35	96.28
95% CI Low	390.70	85.97

Table 16. Scenario 2: Precision Guided Munitions (PGMs) in Theater Distribution Delay between Base Case and Excursion 2-1

e. Ordnance CONSOLs

As expected from the earlier analysis of the ordnance level percentages, the HSVs of this excursion show little impact overall on ordnance CONSOLs. Table 17 presents numbers of ordnance CONSOLs and quantity of ordnance transferred by each T-AE and HSV for both cases of Scenario 2. In Scenario 1, the HSVs were able to reduce T-AE CONSOL requirements by 40% and provided more than half the total ordnance tonnage. In Scenario 2, the HSVs produced no reduction in T-AE CONSOL requirements and moved only 17% of the total ordnance tonnage. The small cargo capacity of the HSVs operating at long range negated much of the "virtual capacity" effects seen in Scenario 1. Several factors combine to limit the HSV benefit in this scenario. In addition to the reduction in the HSV's total cargo capacity, the longer cycle times allow more PGMs to build-up at the FLS for HSV distribution. When this greater quantity of higher priority PGMs is loaded on the HSV, there is little, if any, capacity left for general ordnance.

	Ordnance CONSOLs			
	Guam Base Case		Excursion 2-1	
T-AEs	**Events**	**Tonnage(stons)**	**Events**	**Tonnage (stons)**
Kilauea (T-AE 26)	3	7,261	3	6,583
Shasta (T-AE 33)	6	12,693	6	11,987
Kiska (T-AE 35)	3	6,842	3	5,931
TOTAL	*12*	*26,796*	*12*	*24,501*
HSVs				
HSV 1	-	-	11	2,633
HSV 2	-	-	10	2,602
TOTAL	-	-	*21*	*5,235*

Table 17. Scenario 2: Ordnance CONSOLs between Base Case and Excursion 2-1

V. CONCLUSIONS AND RECOMMENDATIONS

A. ANALYTICAL CONCLUSIONS

HSVs are effective logistics platforms in specific scenarios with limited tasks. This thesis has attempted to better define and narrow the boundaries on the region of HSV logistics effectiveness. The analysis indicates the general areas of potential HSV effectiveness are the same as initially expected: high priority material, ordnance, and stores. These are either required less often and in smaller quantities than other commodities, or have a time component that drives the need for rapid delivery. Also as expected, the HSVs can be highly effective in small theaters with short transit distances, but for larger theaters, their effectiveness is inversely proportional to the distance from the Forward Logistics Site (FLS).

The niche mission where HSVs appear to be most effective is theater distribution of "low density, high priority" cargo; whether that cargo is precision guided munitions (PGMs), critical repair parts, or people should not matter. This holds true in small theaters (e.g., Korea or the Arabian Gulf), where specifically tasked HSVs can deliver the "low density, high priority" material up to ten times faster than current CLF, and in larger theaters, where up to four times faster is still possible. This area of "customer service", of the most concern to COMLOGWESTPAC, is also the area that shows the most benefit from HSVs. The improvements gained from HSVs should be the most apparent for cargos too large for COD, distances greater than COD range, or for ships not operating with a CSG.

The single most effective implementation of this "low density, high priority" mission is use of HSVs for combat delivery of critical stocks of limited supply PGMs to the aircraft carriers. As PGMs continue to become more expensive and/or incorporate the absolute latest technology, fewer can be procured and staged forward. Additionally, as current military operations consume PGMs rapidly, the Navy could expend all ready stocks and be forced to rely on currently open production lines or limited CONUS stocks, meaning fewer weapons available worldwide. Using HSVs as a rapid distribution medium permits possible paradigm shifts in how the Navy procures and stockpiles precision weaponry. Further analysis of centrally stocked, rapid distribution of PGMs must be performed to determine if the Navy can gain large efficiencies in PGM supply with no loss of tactical effectiveness. This, of course, relies on many factors other than HSVs, the most critical of which is dedicated and reliable military airlift sorties supporting Navy ordnance, which would be difficult to obtain.

In small theaters with a nearby FLS, such as around Korea, in the Arabian Gulf, or within the Mediterranean, HSVs have additional capabilities. Not only do HSVs allow the naval logistics system to "touch" each customer every 36-48 hours, but their speed also gives them "virtual capacity", allowing them to replace some larger current CLF shuttle ships. Specifically, HSVs can act in place of, or in augmentation to, ammunitions ships (T-AEs or T-AKEs). Their ability to do so will vary with the nature of the theater, but in small theaters, ratios should range from one to two HSVs for each T-AE replaced. It is critical to note that this capability evaporates with distance from the FLS. At some distance particular to the theater and operations, the "virtual capacity" will fall below the quantity that is sufficient to sustain the combat forces because the hits simply are not large enough. A recent Fleet Forces Command (FFC) study indicated that a much larger HSV to T-AKE replacement ratio was appropriate. FFC's assumption of longer HSV load times and extension of this ratio outside small theaters drives their larger ratio. In fact, the results from Scenario 2 of this analysis, indicating poor HSV ordnance resupply performance at 1800nm ranges, might call into question the validity of any reasonable HSV to T-AKE replacement ratio for long ranges.

Low requirements for stores replenishment drives little to no demand for the services of the combat stores ships (T-AFSs). Given these low stores requirements, HSV cargo capacity dedicated to stores combined with oiler (T-AO) stores deck loads should be sufficient to sustain customer ships in a wide variety of scenarios. Dedicating some HSVs to covering the stores missions could allow dedication of the new T-AKEs to ordnance replenishments, thus potentially reducing the total number required.

The long-distance FLS scenario identified serious stresses on the ability of the naval logistics system to sustain operations around Korea. While the distance alone caused much of the difficulties, the hypothetical use of two operations areas on opposite sides of the Korean peninsula effectively doubled the CLF shuttle requirements. In the event that, in any scenario, the Navy is forced to fall back on distant FLSs for support, consideration must be given to simplifying and consolidating naval operations in one area, as the CLF is sized based on the assumption of closer FLSs.

B. RECOMMENDATIONS FOR FURTHER STUDY

There is extensive potential for further work with CLFSAT. Even within the Korea MCO scenarios, there are additional questions that could be answered. Given more time, many of these cases would have been presented here. Suggestions for additional analysis include HSV ability to service independent groups with no CLF station ships (ESGs, SSGs, or independent ships), further investigation of the limitations of HSV ability to replace T-AEs or T-AKEs, an effort to force T-AFS or T-AKE cycling in CLFSAT to better represent current operations, and an investigation into the effects of sea state on HSV logistics support as compared to standard CLF shuttle ships. CLFSAT is also envisioned as a general purpose analysis tool for naval logistics and has been written to support this. Additional refinements and tweaking of algorithms is required to fully attain this goal.

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LIST OF REFERENCES

1. Commander, Logistics Group, Western Pacific. "Command Mission." http://www.clwp.navy.mil/mission.htm. Jan. 2005.

2. Csontos, Aladar A., and Burnham C. McCaffree, Jr. "The Combat Logistics Force Response to Operation Enduring Freedom." CRM D0007211.A2/Final. Center for Naval Analyses, Alexandria, Mar. 2003.

3. Douglas, Carl. "Operation Iraqi Freedom: Combat Logistics Force Operations Quicklook." CAB D0008768.A2/Final. Center for Naval Analyses, Alexandria, Sep. 2003.

4. Clark, ADM Vern, USN. "Persistant Combat Power," *United States Naval Institute Proceedings*, Vol.129, Iss. 5, pg. 46. Annapolis, May 2003.

5. Naval Warfare Development Command. "High-speed Vessel (HSV): Adaptability, Modularity, and Flexibility for the Joint Force." http://www.nwdc.navy.mil/Concepts/Sea_Basing/ConceptsHSV.aspx. Jan. 2005.

6. Higgins, Sean P., and David A. March. "Analysis and Evaluation of High-speed Ferries in Support of Joint Logistics Over-The-Shore." Masters Thesis, Naval Postgraduate School, Monterey, California, Mar. 2002.

7. American Institute of Marine Underwriters (AIMU). "High-speed Craft." http://www.aimu.org/hsc.html. Jan 2005.

8. Strenge, Thomas, and Kevin W. Ralston. "The Costs and Benefits of High-speed Vessels Relative to Traditional C-17 Military Airlift." MBA Professional Report, Naval Postgraduate School, Monterey, California, Dec. 2003.

9. Incat. "Defense-Military." http://www.incat.com.au/defence_fs.html. Jan. 2005.

10. High-speed Connector Integrated Process Team (HSC IPT). "High-speed Connector Concept of Operations V2.0." Washington D.C., Apr. 2004.

11. Smith, Wayne J., Michael W. Price, and Charles H. Douglass. "Application of Speed in Naval Vessels -- Summary." CAB D0007950.A2/Final. Center for Naval Analyses, Alexandria, May 2003.

12. Douglas, Carl. "Quicklook Investigation of a High-Speed Vessel's Utility as a Combat Logistics Force Ship." CAB D0007814.A2/Final. Center for Naval Analyses, Alexandria, Apr. 2003.

13. Stewart, George M. "At-Sea Experimentation with Joint Venture, October 2001 through September 2002." CAB D0007793.A2/Final. Center for Naval Analyses, Alexandria, Mar. 2003.

14. Rudko, David D. "Logistical Analysis of the Littoral Combat Ship." Masters Thesis, Naval Postgraduate School, Monterey, California, Mar. 2003.

15. Savitch, Walter. *Java – An Introduction to Computer Science and Progamming.* Upper Saddle River: Prentice Hall, 2001.

16. Borden, Kevin D. "Optimizing the Number and Employment of Combat Logistics Force Shuttle Ships, with a Case Study of the T-AKE Ship." Masters Thesis, Naval Postgraduate School, Monterey, California, Sep. 2001.

17. Givens, Ronaldo D. "A Comparison of the Operational Potential and Capability of Two Combat Logistics Force Alternatives." Masters Thesis, Naval Postgraduate School, Monterey, California, Sep. 2002.

18. Cardillo, John A. "Optimizing Global Operations Plans for the Combat Logistics Force." Masters Thesis, Naval Postgraduate School, Monterey, California, Sep. 2004.

19. Chief of Naval Operations Staff, Navy Strategic Mobility and Combat Logistics Department (OPNAV N42). "Model Ship Assumption Inputs Spreadsheet." Washington, D.C., Dec. 2004.

20. Siegrist, Kyle. "Virtual Laboratories in Probability and Statistics: Poisson Process – Estimating the Rate." http://www.ds.unifi.it/VL/VL_EN/poisson/poisson4.html, Mar. 2005.

21. Schrady, David A., Gordon K. Smyth, and Robert B. Vassian. "Predicting Ship Fuel Consumption: Update." Technical Report NPS-OR-96-007, Naval Postgraduate School, Monterey, California, Jul. 1996.

22. Schrady, David A. "Analysis of Carrier Air Wing Sortie Rates and Fuel Use." Technical Report NPS-OR-93-005, Naval Postgraduate School, Monterey, California, Nov. 1992.

23. Priority Material Office. "PAC W-Requisitions Spreadsheet." Bremerton, Washington, Feb. 2005.

24. Commander, Naval Air Forces. "CNAL W-Requisitions Spreadsheet." San Diego, California, Feb. 2005.

25. GlobalSecurity.org. "Smart Weapons." http://www.globalsecurity.org/military/systems/munitions/smart.htm. Mar. 2005.

26. Witt, LCDR Bruce. "JDAM Kit Weights." Email, 2 Mar. 2005.

27. Futcher, LCDR Frank W. "Iron Triangle curves corrected for LT and 10% fuel margin." Email, 28 Dec. 2004.

28. Tyler, Patrick E. "7 Hypothetical Conflicts Foreseen by the Pentagon." *New York Times*. New York, 16 Feb. 1992.

29. GlobalSecurity.org. "Korea Crisis – Military Options." http://www.globalsecurity.org/military/ops/korea-options.htm, Mar. 2005.

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